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13. ABSTRACT (Maximum 200 words)

This project developed a criterion-free vision training test to improve contrast sensitivity in normal and abnormal vision. The scientific development, evaluation and refinement of noninvasive techniques for improving contrast sensitivity is important since contrast sensitivity is predictive of much everyday visual performance. Two novel techniques of contrast sensitivity training were tested. Static contrast sensitivity at low and high spatial frequencies was first measured and then trained on a CRT display. Additional measures were obtained before and after training on a contrast sensitivity test chart and on detection and discrimination of complex targets. Large increases in contrast sensitivity due to vision training were found in some normal and amblyopic observers. There were large individual differences in the amount of improvement on contrast sensitivity and performance tasks. Increased contrast sensitivity ranged from 11.5% to 69.2% in normals and from 1.5% to 69.5% in amblyopes. Improvement in detection and discrimination of real-world targets ranged from 0% to 81.2% in normals and from 0% to 96.2% in amblyopes. These results suggest that two-alternative forced-choice methods are effective training procedures in many normal and amblyopic observers.

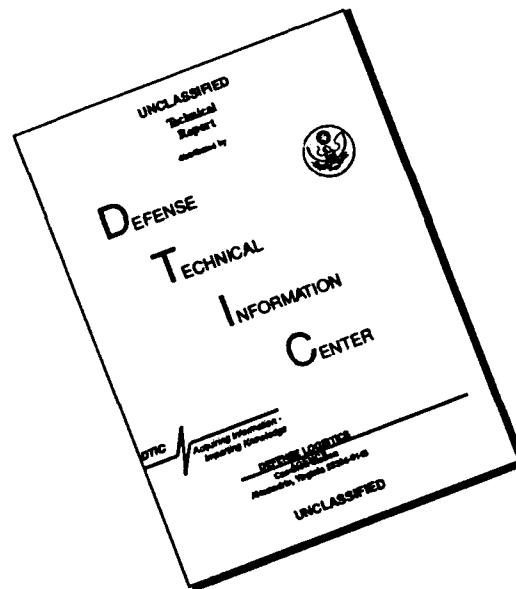
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Introduction

Current models of human spatial vision assume that the visual system processes spatial information about complex objects using mechanisms that can be described in terms of spatial frequency or size filters. (Spatial frequency is defined as the number of light and dark bars present within one degree of visual angle.) The contrast detection threshold for a single spatial frequency stimulus represents the sensitivity of a specific subset of visual mechanisms selectively responsive to that spatial frequency.

Contrast sensitivity is the inverse of the contrast detection threshold. When contrast sensitivity is plotted as a function of spatial frequency, the resulting curve represents an envelope of the separate sensitivities of spatial frequency mechanisms. There are large individual differences in contrast sensitivity in the normal population (Ginsburg et al., 1983), but in general the contrast sensitivity curve is bell-shaped. Deficits in spatial frequency mechanisms in the visual system can then be discovered through investigation of contrast processing in normal vs. abnormal vision (Arden, 1978; Bodis-Wollner and Camisa, 1980; Hess and Woo, 1978).

Vision Training and Contrast Sensitivity

Certain optometrists recognize that visual capability can be improved with training (Bobier and Sivak, 1983; Cooper and Duckman, 1978; Cornsweet and Crane, 1973; Daum, 1982, 1983; Griffin, 1982; Pierce and Greenspan, 1971; Sheedy, 1950; Suchoff and Petito, 1986; Weisz, 1979, 1983). Vision training is used to overcome many visual disorders and dysfunctions including amblyopia. This is important since estimates of the prevalence of amblyopia in the United States range from 2% (Flom and Neumaier, 1966) to 8.3% of the population (Rubenstein et al., 1985; Ross et al., 1977).

A standard, and relatively successful procedure to improve amblyopia is occlusion therapy (Brown and Edelman, 1976; Eibschitz et al., 1978; Garzia, 1987; Gortz, 1966; Gregersen, 1966; Haldi and Mitchelson, 1981; Massie, 1965; Nawratzki, 1972; Scott et al., 1980). However, there are patients who do not benefit from this procedure. Often an active vision training procedure is used in conjunction with occlusion therapy, such as pleoptics (e.g., Francois and James, 1955). In pleoptics, the patient receives visual feedback as to their fixation position since there is evidence that unsteady eye movements occur in the eyes of amblyopic patients during attempted monocular fixation (Schor and Flom, 1975).

Measures of contrast sensitivity have been shown to be useful in the assessment of visual function in functional amblyopia (e.g., Hess and Howell, 1977; Bradley and Freeman, 1981). It has been proposed (Hess and Howell, 1977; Bradley and Freeman, 1981) that both strabismic and anisometropic amblyopes can be characterized

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as either having a high spatial frequency deficit (Type I) or loss at the lower and higher spatial frequencies (Type II). Occlusion therapy has been used as a training technique for strabismic and anisometropic amblyopia (Leguire et al., 1987). During the course of one to three month occlusion therapy there is a reduction in deficits seen at low spatial frequencies. Contrast sensitivity increases an average of 485% at lower spatial frequencies and 383% at higher spatial frequencies. Whether the observer has strabismic or anisometropic amblyopia as well as their initial acuity, must be considered to predict pre- and post-training scores on contrast sensitivity (Leguire et al., 1989).

Another form of vision training, repetitive practice, often results in substantial improvement in normally sighted observers. Effective vision training consisting of a repetitive testing technique has been shown for the peripheral localization of targets (Ball, Beard, Roenker and Miller, 1987, 1988), motion discrimination (Ball and Sekuler, 1982), spatial discrimination (Ball, Beard and Pasley, 1988), vernier acuity (McKee and Westheimer, 1978) and contrast sensitivity (DeValois, 1977; Kelly et al., 1984; Kelly and Tomlinson, 1987; Ginsburg, 1978).

The results of studies investigating the effects of repetitive practice on contrast sensitivity are as varying as the methods used. The method of adjustment (DeValois, 1977; Ginsburg, 1978; Kelly et al., 1984) has been successful in showing improvement after training while a modified von Békésy method has not been successful (Kelly and Tomlinson, 1987). The duration of successful studies range from one month to 1.5 years while in the modified von Békésy study, training continued for only five consecutive days. It is possible that sequential training is not as effective as more infrequent training. Advantages and disadvantages of these techniques will be discussed in a later section.

Two studies have investigated the effects of repetitive practice on contrast sensitivity in amblyopes (Ginsburg, 1978; Lennerstrand and Lundh, 1979). Using the method of adjustment, Ginsburg (1978) found improvement at middle and high spatial frequencies. Amblyopia was treated using the method of grating stimulation by Lennerstrand and Lundh (1979) who also found the greatest amount of improvement at middle to high spatial frequencies.

These examples of improved vision strongly suggest that training techniques can be developed for certain visual functions. Relatively little research has been devoted to the development and refinement of techniques for the improvement of spatial contrast processing. This is of major significance since contrast sensitivity has been shown to be predictive of whether or not an individual will have problems seeing objects in everyday contexts (Ginsburg, 1978). For example, contrast detection thresholds have been shown to be related to the detection and identification of

complex targets such as letters (Ginsburg, 1978, 1986), faces (Owsley et al., 1981), aircraft (Ginsburg et al., 1982, 1983) and other military targets (Shinar and Gilead, 1987; Stager and Hameluck, 1986).

Thus, an individual showing a depression in the contrast sensitivity curve within a particular spatial frequency range will show decrements in everyday visual performance on a task requiring the visual mechanisms responsible for the depression. If selective improvement in contrast sensitivity is possible, then problems experienced in everyday visual tasks may be helped through vision training. DeValois (1977) suggested that contrast sensitivity training could result in a change over time in the sensitivity profiles of the spatial mechanisms. Another possible consequence of training could be in the establishment of new connections between existing mechanisms.

Contrast sensitivity improvement is vital for individuals with vision intensive occupations such as pilots, photo interpreters and radiologists, and is especially important for enhancing the vision of those with average or below average vision. Training procedures may improve vision from low-normal to high-normal ranges, making good vision even better and resulting in better visual performance.

The major aim of this project was to develop a criterion-free, micro-computer based vision training test designed to improve contrast sensitivity. Static contrast sensitivity was first assessed and then trained on a CRT display using a repeated contrast sensitivity testing (RCST) technique. Additional measures were obtained on the Vision Contrast Test System (VCTS) chart before and after training. Chart measurements were taken to determine if improvements in contrast sensitivity are easily estimated in a chart format. It was then determined if these improvements in contrast sensitivity, as seen on the CRT and VCTS, consequently improve functional capabilities required for real-world target detection and discrimination. Phase I research saw the development of two training techniques and pilot studies were performed using normal and clinically abnormal (amblyopes) observers.

Development of the RCST Technique

The first step taken in the development of a contrast sensitivity training technique in this Phase I research was to examine the advantages and disadvantages of previously employed techniques. Three general techniques have been used: grating visual stimulation, a modified von Békésy tracking method and the method of adjustment.

Lennerstrand and Lundh (1979) found significant increases in contrast sensitivity in amblyopic children after grating visual stimulation training. Observers were exposed to high contrast

grating stimuli for ten-minute periods twice a week. This training technique was conjunctively used with occlusion therapy in many of these children. Since occlusion therapy alone has been shown to increase contrast sensitivity in some children (Leguire et al., 1987), it is unclear whether the occlusion therapy or grating stimulation caused the increases found in contrast sensitivity.

In the modified von Békésy tracking technique, grating contrast is initially set below contrast threshold, then is gradually increased until the observer depresses a response button that causes the contrast of the grating to gradually decrease until it can no longer be seen. At this time the observer releases the response button and the grating contrast again gradually increases. This procedure is repeated until a set number of reversals in contrast are achieved. The geometric mean of these reversals constitutes the contrast threshold.

Using a modified von Békésy tracking method, Kelly and Tomlinson (1987) found no significant effect of training when contrast thresholds were averaged in 20 observers. Since individual data was not discussed, it is possible that the procedure was effective in some of the 20 observers who participated in this study. In addition, observers were trained only for approximately 15 or 30 minutes over five consecutive training days. More prolonged training on each day could have resulted in significant training effects.

Although the modified von Békésy tracking method rapidly tracks contrast threshold, the variability of the test is high (Kelly and Tomlinson, 1987). This may result in the technique being less sensitive if the increase in contrast sensitivity after training is small. Since Kelly and Tomlinson (1987) trained young observers for a short period of time, any increase in contrast sensitivity would be obscured by the large degree of variability in the scores. It is also possible that training on consecutive days is not as effective as staggering the training days.

Improvement in contrast sensitivity is also seen using the method of adjustment (DeValois, 1977; Ginsburg, 1978; Kelly et al., 1984). In this method the observer simply adjusts (usually by turning a knob) the contrast of a grating pattern until it is just visible. Although this method has the advantage of being quick, similar to the von Békésy tracking method, it has the disadvantage of providing very little control over the observer's response criterion. Since an observer's response criterion can change from one trial to the next, data obtained using the method of adjustment could show large variability. This variability would tend to obscure training effects unless a large number of measurements were taken in each session.

An observer's response criterion is assumed to be constant throughout a block of trials using forced-choice designs (Swets, 1964). Forced-choice designs can either involve the method of constant stimuli or an adaptive method (Graham, 1989). In the method of constant stimuli, the contrast of a pattern is decided beforehand and each is presented a given number of times. In adaptive methods, the contrast of the pattern on a particular trial is determined by the observer's responses on previous trials. For example, the contrast may be increased when the observer makes an error and decreased when the observer is correct several times in a row. The contrasts on different trials form a "staircase" going up and down around the threshold.

Since previous studies have suggested that contrast sensitivity is plastic, Phase I research was developed to determine a practical and effective method for the improvement of contrast sensitivity. A repeated contrast sensitivity testing technique (RCST) was used to determine the degree contrast sensitivity could be improved in normal and clinically abnormal subjects. This research compared two criterion-free forced-choice procedures: the method of constant stimuli and staircase method.

Grating stimuli were presented on a cathode-ray-tube (CRT). The RCST training technique involved the repeated presentation of two stimulus intervals: one interval contained a low contrast grating, while the other interval was blank. The observer's task was to determine, for each stimulus pair, which interval contained the stimulus. Auditory feedback was provided for correct responses. Each test session continued for one full hour and multiple test sessions were performed on nonconsecutive days.

Two spatial frequencies were trained to determine the spatial frequency selectivity of training effects. Trained stimuli were widely separated in spatial frequency: either 3.0 or 12.0 cpd. Observers were randomly trained on one of these two frequencies and tested at other spatial frequencies to measure any transfer in training to these other spatial frequencies.

Three specific questions were addressed in the present research:

(1) Was there a significant amount of improvement in contrast sensitivity at the trained spatial frequency after training on the CRT?

To define the amount of improvement considered significant using the RCST, the expected amount of improvement can be determined from previous data reported in the literature. DeValois (1977) collected contrast sensitivity data on two normal observers over a 1.5 year period. The results indicate that there was a gradual, monotonic increase in contrast sensitivity over time. At 3.0 cpd, there was an approximate 401.2% improvement and at 12.0 cpd the amount of improvement in contrast sensitivity was 77.8%.

Since Phase I training reported here continued over approximately a one month period, linear interpolation of the amount of improvement seen over one month from the DeValois study is warranted since improvement was gradual over the 1.5 year time period. This linear interpolation predicts improvement over one month of 22.3% at 3.0 cpd and 4.3% at 12.0 cpd.

The amount of improvement expected for amblyopic observers can be generally assumed from the work of Ginsburg (1978) who collected contrast sensitivity measurements on a 20 year old amblyope over a 34 week period. In the amblyopic eye, this observer demonstrated 266.2% improvement at 3.0 cpd, and a 769.0% improvement at 12.0 cpd. Interpolation of the data predicts a 31.3% improvement at 3.0 cpd and 90.5% improvement at 12.0 cpd over a one month period.

Thus, from these two data sets it was predicted that if the present training techniques are successful, normal observers should show at least 20% improvement at 3.0 cpd and 4% improvement at 12.0 cpd. Amblyopes, on the other hand, should show greater improvement at both spatial frequencies: at least 30% at 3.0 cpd and 90% at 12.0 cpd.

The second question addressed in the present research is:

(2) Can this improvement be seen in an easily administered chart format?

If improvement in contrast sensitivity observed after training on the CRT was found to be similar on the VCTS chart, then training as well as the extinction of training can be easily monitored using the chart. In this way, it can be easily known how often to repeat training on the CRT in order to sustain the training effects.

(3) Do these improvements extend to performance measures?

Contrast sensitivity has been shown to be predictive of the ability to detect and discriminate everyday objects. Based on this, it would be expected that improvement in contrast sensitivity should extend to everyday performance measures. A means of determining the expected amount of improvement in performance after contrast sensitivity training is to establish the percentage difference in contrast sensitivity and performance measures for observers with low contrast sensitivity as compared to observers with high contrast sensitivity from previous research.

In an investigation which tested the relationship between contrast sensitivity and a pilot's ability to detect small air-to-ground targets in a flight simulator, Ginsburg et al. (1981) found a difference in contrast sensitivity between two pilots of 195.8% and in target detection range of 120%. These differences in contrast sensitivity and visual performance in these two pilots support the relationship between contrast sensitivity and

performance in complex visual conditions. These data also support the issue of individual differences in the contrast sensitivity of normal observers being related to visual performance.

Reports in the literature suggest an age difference in contrast sensitivity. At mid and high spatial frequencies, the contrast sensitivity of young observers is 25% higher than that of older observers (Owsley et al., 1983; Evans and Ginsburg, 1985). In addition, young observers are able to discriminate road signs at a distance 24% further than older observers (Evans and Ginsburg, 1985). These age differences resulting in contrast sensitivity and performance losses further support the important relationship between visual performance and contrast sensitivity.

In the performance battery used here, a decline in contrast sensitivity was simulated using haze lenses, which diminished visual capability and resulted in a 35% decrement in both contrast sensitivity on the VCTS chart and performance measures. Thus, based on these results, and the results of previous investigations, a minimum of 25% improvement in performance scores from the contrast sensitivity training is considered significant.

The main goals established and accomplished in this research were to:

1. Complete a literature search. References were found using DIALOG informational services for the integration of the visual scientific and clinical literature important to the plasticity of visual mechanisms and vision training as it relates to contrast perception.
2. Develop computer programs for training. Two computer programs were written (in Turbo C language). One program trains contrast threshold using a two-alternative forced-choice staircase procedure. The second program incorporates a two-alternative forced-choice training procedure using the method of constant stimuli.
3. Design experiments to implement the training procedures and collect data to test their effectiveness. Two pilot experiments were performed during Phase I. In the first, only normally sighted individuals were trained in order to better refine the experimental techniques. The second pilot experiment used the information gathered in the first experiment for the development and testing of an effective RCST technique in normal and clinically abnormal observers.

Each training experiment consisted of a three step process:

- a. Pre-training: including measures of acuity, contrast sensitivity on the VCTS, contrast sensitivity on a CRT and performance measures including the detection and discrimination of real-world objects.
- b. Training: repetitive contrast sensitivity testing on the CRT over nonconsecutive test days.
- c. Post-training: measures were again obtained as in pre-training.

By pre-testing on a variety of tasks, training on one of the tasks, and then post-testing performance on the original tasks, the training technique showing appreciable transfer to visual performance was assessed.

Methods

Experiment 1 (Group A)

Observers. Six observers with normal vision, ages 22 to 51 (mean age 39.83 years old) were tested. Written informed consent was obtained from each participant.

Procedure. Pre- and Post-training

Four separate measures were obtained during pre- and post-training sessions: monocular visual acuity, monocular contrast sensitivity using the Vision Contrast Test System (VCTS), monocular contrast sensitivity using a CRT display and performance measures on face and letter detection and discrimination. The order of testing on these four measures was randomized.

Monocular visual acuity was measured in both eyes using the Lighthouse Visual Acuity Test (modified ETDRS) with Sloan letters. Chart luminance was 170 cd/m². The average monocular acuities (minimum angle resolvable) before training for the normal observers was 1.00 (OD, SD=.001) and 0.875 (OS, SD=.02).

Monocular contrast sensitivity measurements were obtained using the VCTS chart. Three measurements were made for each eye using the three versions of the test chart, each version having different randomly oriented gratings to help prevent memorization. Contrast sensitivity measures were taken on 1.5, 3.0, 6.0, 12.0 and 18.0 cpd sinusoidal grating patterns. The procedure used was that recommended by the manufacturers. Mean luminance of the charts were 144 cd/m².

Contrast thresholds were also measured for real-world targets: faces and letters. These targets were displayed on slides. In any one experimental session, either faces or letters were tested. Order of testing was randomized. The face targets were faces of children recruited from a local nursery school. Letters were helvetica type. Each slide contained either two faces or two letters. Half of the slides were of the same person or letter and the other half were different.

It was desired to train contrast sensitivity on two widely separated spatial frequencies to determine the spatial frequency selectivity of the training effects. From previous studies (Ginsburg, 1978), larger faces would require relatively low spatial frequencies for discriminations, small letters would require high spatial frequencies. The relevant spatial frequency required to detect and discriminate the faces and letters were determined in order to select the spatial frequencies used to train the observers and to determine the effect of training on performance. Face targets were relatively large and subtended 10 degrees of visual angle. Letters subtended 0.083 degrees of visual angle (5.0 min). To determine the appropriate spatial frequency of these targets, an adaptation experiment was performed. Two observers initially adapted for five minutes to sine wave gratings of either 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 10.0, 11.0, 12.0, 13.0, 14.0 or 15.0 cpd. Order of testing was randomized. Immediately following adaptation, observers were asked to indicate when they could just detect the presence of either a face or letter. Following the detection threshold estimate, the contrast of the target was increased until the observer could correctly discriminate whether the same or different face (or letter) was being presented. Two measurements were taken on each of the twelve adapting frequencies. Slides of faces were found to be optimally effected by adaptation to a 3.0 cpd grating stimulus and letters were optimally effected by adaptation to a 12.0 cpd stimulus.

Slides of these targets were projected through an optical system which allowed the experimenter to adjust the contrast of the target's image (Ginsburg, 1978). This projection system consisted of two slide projectors positioned so that their beams combined on a front projection screen. Fixed linear polarizers were positioned in front of each projector in orthogonal positions. One projector contained the target slide, while the other projector had an open aperture. Another polarizer intersected the two beams before they reached the screen. This polarizer could be rotated in order to control the amount of light which came from each of the two slide projectors. In this way, the target contrast could vary from zero contrast to 0.90 by repositioning the polarizer.

In the performance tasks, viewing was monocular. Both eyes were tested separately. The observers indicated when something was just detectable on the screen as the experimenter adjusted the polarizer and increased contrast. The experimenter then recorded

the position of the polarizer. The subject was then asked to indicate when they could discriminate whether the stimuli shown were the same face or letter or whether they were different. In this way both a measure of detection and discrimination thresholds were obtained. These threshold measurements were determined for five slides of each target type (faces or letters). Detection and discrimination performance was defined as the mean of these five repeated contrast measurements.

Contrast sensitivity measurements in each eye were also obtained for 3.0 and 12.0 cpd sinusoidal grating stimuli on an electronic display system using either a two-alternative staircase or method of constant stimuli similar to the RCTS used for that observer. Mean luminance of the display monitor was 40 cd/m². Eight total measurements were taken per observer (2 repetitions, 2 spatial frequencies, 2 eyes). The procedure is outlined in detail below.

Training

After initial pre-training, each observer was randomly placed into one of four training groups. In order to determine whether training effects were specific to the trained spatial frequency, observers were either trained on 3.0 or 12.0 cpd. These frequencies correspond to the effective spatial frequency of the face and letter targets, respectively. To determine the training effectiveness of the two different methods, observers were either trained using a two-alternative forced-choice staircase procedure or the method of constant stimuli.

The observers were randomly assigned to either the staircase or constant stimuli training conditions. In both of these methods, observers viewed the display monocularly at a test distance of 118 cm. A handheld keypad, consisting of two labeled buttons was used. Observers pushed one of these keys to initiate the procedure. One trial consisted of two 500 msec intervals, signaled with tones. The observer made a single response after each trial. Only one interval contained a grating stimulus and observers were asked to determine in which interval the stimulus was presented. In the staircase method, if the subjects response was correct four times in a row, the contrast of the target was then decreased by one quarter log unit. If incorrect, the contrast would be increased by the same amount. This resulted in correct detection of the stimulus on 84% of the trials. Correct responses were marked by an auditory tone. After the completion of 12 reversals in contrast (e.g., increase, decrease, increase ...) the mean contrast of the peak threshold was defined as the contrast threshold for that condition.

In the method of constant stimuli, the observer first determined his threshold using the staircase procedure for that frequency in a single session (2 repetitions). This threshold was used throughout the remainder of the experiment. In the method of

constant stimuli, one block consisted of 50 two-alternative trials. The observer indicated in which interval a stimulus was presented. Correct responses were signaled by an auditory tone.

Results (Group A)

In the following section, the general effects of training for each method on individual observers will be discussed first because of large individual differences. General conclusions from this pilot work will then be summarized.

Staircase Method

Figure 1 presents the data for observers JC, CH and PM before, during and after training using the staircase tracking method. Sensitivity to contrast is plotted as a function of the day of testing. The trained spatial frequency and trained eye data is shown as filled circles. Only pre- and post-training measurements were taken for the remaining conditions (e.g., untrained spatial frequency, untrained, other eye). Open circles show the data for the untrained eye and trained spatial frequency, open squares show the data for the untrained eye and untrained spatial frequency and filled squares show the data for the trained eye and untrained spatial frequency. It can be seen that for all three observers there was improvement using this training method. For observer JC contrast sensitivity increased from 105.6 to 177.4 (67.9% increase), for CH from 99.7 to 149.2 (49.6% increase) and for observer PM from 79.1 to 93.9 (18.8% increase). Thus, the contrast required to detect the trained sinusoidal stimulus in the trained eye for these three observers did increase over the ten training days.

Figure 2 presents the data for the same three observers showing the percent of improvement in pre- versus post-training scores as a function of the task (i.e., VCTS, CRT, acuity, facial and letter detection and discrimination). Open bars represent data for the trained eye. The untrained eye is shown by filled bars. The data for each observer will be discussed in turn.

Observer JC (top panel) is a 48 year old male who was trained using the staircase method at 3.0 cpd. VCTS scores showed improvement at the trained spatial frequency (28.4%), two surrounding frequencies (1.5 cpd = 57.7%, 6 cpd = 48%) and at 18 cpd (58.8%). Contrast sensitivity as measured on the CRT showed the greatest improvement at the trained spatial frequency in the trained eye (67.9%). There was no improvement observed in his acuity score. The greatest improvement seen in the performance measures was on the discrimination of both faces (29.3%) and letters (27.5%) in the untrained eye. Possible explanations for these results will be discussed below.

Observer CH (center panel of Figure 2) is a 51 year old female trained using the staircase method on a 3.0 cpd stimulus. Her VCTS scores showed the greatest improvement (about 100%) at 3.0 cpd for both the trained and untrained eye. In addition, 49.6% improvement in contrast sensitivity as measured on the CRT was selective to the trained eye and trained spatial frequency. Again there was no improvement in acuity. Although the greatest improvement in the performance measures was for facial discrimination (115%) in the untrained eye, the trained eye also showed 81.2% improvement.

Observer PM (bottom panel) is a 48 year old female trained on 12.0 cpd using the staircase method. Contrast sensitivity measured on the VCTS chart showed the greatest improvement at 1.5 (48.4%) and 18.0 (68.7%) cpd in the untrained eye. The trained eye did show 88.3% improvement on the CRT at 3.0 cpd with only 18.8% improvement observed at the trained spatial frequency. This observer demonstrated improved acuity in both eyes perhaps because she was trained at a high spatial frequency. Performance measures revealed 41.7% improvement only in the discrimination of faces in the untrained eye.

Method of Constant Stimuli

Figure 3 shows the percent correct responses across testing days for observers JS, HK and AC. Observers JS (48 year old male) and HK (22 year old female) were trained using the method of constant stimuli at 3.0 cpd. Observer AC, a 22 year old female, was trained using the same method at 12.0 cpd. JS demonstrates a decline in the percent correct responses from 75% to 56% (33.9% deficit). One reason for this unexpected decline in percent correct responses could be because the contrast level at which the observer was being trained may not have been substantially visible. This might have occurred since only two threshold tracking measures were averaged to determine the contrast level of the remaining training sessions. We address this potential problem later. Observer HK shows substantial improvement from 57.6% to 92% correct responses (59.7% improvement). Observer AC shows a general trend in her responses over training days, if days 7 and 9 are excluded, demonstrating improved performance between pre- and post-training days from 76% to 96% correct responses (26.3% improvement). On days 7 and 9, observer AC complained of not feeling well which could have elevated contrast threshold.

As shown in Figure 4, selective improvement was not seen in these three observers for the trained spatial frequency on the VCTS chart or CRT. All showed no significant improvement in acuity. Performance measures revealed 18.7% improvement for the discrimination of faces for observer JS, 43.1% improvement in the discrimination of faces for observer HK and minimal improvement in both face and letter detection and discrimination for observer AC.

This lack of selectivity is not what would be expected if the training procedure was effective. Possible problems with the experimental procedure will be discussed below.

General Findings (Group A)

Staircase Method

1. Observers trained on 3.0 cpd using the staircase method on the CRT showed on average 58.7% improvement in detection thresholds at the trained spatial frequency in the trained eye versus 19.6% improvement in the untrained eye.
2. Two observers (JC and PM) showed no consistent improvement on VCTS scores. Observer CH (trained at 12.0 cpd) showed 71.6% improvement on the trained spatial frequency.
3. Individuals trained at both 3.0 and 12.0 cpd showed improvement on the discrimination of faces. This questions the relationship between the spatial frequency selectivity of this improvement to task performance. One reason for this lack of selective improvement may be the paradigm used in this study. Features such as hair, size and build could be learned by the post-training period since the same slides were used for pre- and post-training measures.
4. Most (72%) of the training using the staircase method occurred within the first six training days.
5. Two observers trained at 3.0 cpd using the staircase method showed no improvement in acuity scores, however the acuity scores did improve for the observer trained at 12.0 cpd using this method. This would be expected since both the detection of 12.0 cpd gratings and acuity tasks require the ability to discriminate fine detail.

Method of Constant Stimuli

1. None of the three observers showed an increase in sensitivity at the trained spatial frequency on the VCTS chart. There are two possible explanations for the results. First, two observers, HK and AC, were 22 year olds whose initial visual sensitivity (contrast threshold) left little room for improvement (Figures 5 and 6). The ceiling effect for contrast sensitivity is readily apparent. It is unclear why observer JC did not show selective improvement at 3.0 cpd on the VCTS. One possible reason why the method of constant stimuli may appear to be less effective could be that the contrast at which observers were trained was determined by two repetitions of the staircase procedure. It is possible that more repetitions are needed to accurately track the threshold level at which observers were trained since there is variability in independent threshold measures using the staircase method.

2. It could be expected that observers trained at 12.0 cpd would show improved acuity scores since both tasks require fine detail discrimination, however, no significant increases in acuity scores were found for these observers. All observers began with acuities of 20/20 to 20/15, therefore little improvement could be expected.

Modifications to the Procedure

Based on these results the protocol was modified in the following ways:

1. Performance tasks were administered on a CRT for better control of contrast and image quality. The previous method used a polaroid filter slide projection technique.

2. Six training days were implemented rather than 10 to allow more observers to be trained before the research period ended and since the 72% of the training occurred within the first six training days.

3. The contrast used for training with the method of constant stimuli was determined in an initial session comprising a minimum of ten staircase determinations rather than two as in the preceding pilot study to obtain a more accurate threshold estimate.

4. Only normal observers over the age of 35 were tested. Younger observers generally have greater visual sensitivity (acuity and contrast sensitivity) and provide less room for improvement. This can be seen in Figures 5, 6, and 20-23 which present the contrast sensitivity data for all observers in Group A.

5. Both normal and amblyopic observers were scheduled for training.

Methods

Experiment 2 (Group B)

Observers. Observers were recruited either through a newspaper advertisement or referral by a participating ophthalmologist. Five observers with normal vision, ages 38 to 62 (mean age 47 years old), and five anisometropic amblyopes, ages 14 to 43 (mean age 32 years old), were tested. Written informed consent was obtained from each participant. For the purposes of this study amblyopes underwent detailed ophthalmological examinations, which included direct ophthalmoscopy, biomicroscopy, applanation tonometry, field testing and refraction. Intraocular pressure was found to be within normal limits (≤ 19 mm Hg). All observers wore normal corrective lenses during testing.

Procedure. Pre- and Post-training

Four separate measures were again obtained during pre- and post-training sessions: monocular visual acuity, monocular contrast

sensitivity using the VCTS chart, performance and monocular contrast sensitivity using a CRT display.

Monocular visual acuity was measured in both eyes using a Snellen chart. The average monocular acuities (minimum angle resolvable) before training for the normal observers was 0.89 (OD, SD=.05) and 1.01 (OS, SD=.03). Amblyopic eyes showed MARS of 4.29 and the nonamblyopic eyes were 0.98.

Monocular contrast sensitivity measurements were obtained using the Vision Contrast Test System (VCTS). Three measurements were made for each eye employing the three versions of the testing system. Contrast sensitivity measures were taken on 1.5, 3.0, 6.0, 12.0 and 18.0 cpd sinusoidal grating patterns. Mean luminance of the charts were 144 cd/m².

Contrast thresholds were also measured for images of complex objects: faces, letters and highway signs. These targets were displayed on a computer monitor. Face targets subtended 3.0 degrees of visual angle, letters subtended 0.09 degrees of visual angle and highway signs subtended 3.38 degrees. An adaptation pilot study, as described above, determined that these size targets were strongly influenced by spatial frequencies of 3.0, 12.0 and 3.0 cpd for face, letter and highway signs, respectively. Only one target type was tested in a single session.

In order to maintain similar spatial frequency and contrast of the face targets, faces were of male and female adults with no distinguishing extraneous characteristics. Hair and clothing were masked by a white/grey surround. Letters were helvetica type. Highway signs were either of a right turn, left turn, T intersection or + intersection. Highway signs were added as stimuli to determine the effect of contrast sensitivity training on performance in a driving situation. Each computer screen contained either two faces, two letters or one highway sign. Half of the screens were of the same person or letter and half of the screens were different.

In the performance tasks viewing was monocular. Both eyes were tested. Each target was presented in a randomly determined order. The observers indicated on a response pad when something was just detectable on the screen as the program gradually incremented the contrast of the stimulus in 0.14 contrast steps. The subject was then asked to indicate on the response pad when they could discriminate whether the stimuli shown were of the same face or letter or whether they were different. In this way both a measure of detection and discrimination thresholds were obtained. Highway signs were first detected and then identified by observers. Responses were made on a response keypad. These threshold measurements were determined for eight face sets, seven letter and four highway signs. Detection and discrimination performance was defined as the mean of the repeated measurements.

Contrast sensitivity measurements in each eye were also obtained for 3.0 and 12.0 cpd sinusoidal grating stimuli on a CRT using staircase and method of constant stimuli techniques. Mean luminance of the display monitor was 40 cd/m². Forty measurements were taken per observer (10 repetitions, 2 spatial frequencies, 2 eyes).

Training

After initial pre-training, each observer was randomly placed into one of four training groups. To determine whether training effects were specific to the trained spatial frequency, observers were either trained on 3.0 or 12.0 cpd. To determine the training effectiveness of different methods, observers were either trained using a two-alternative forced-choice staircase procedure or the method of constant stimuli.

The observers were randomly assigned to either the staircase or constant stimuli training conditions. In both of these methods, observers viewed the display monocularly at a test distance of 118 cm. The training procedure is the same as that outlined above, however the number of training days was reduced to six from ten days.

Results (Group B)

Staircase Method

Figure 7 presents the contrast sensitivity data for observers LM, CW and CR before, during and after training using the staircase tracking method. The trained spatial frequency and trained eye data is shown as filled circles. Open circles show the data for the untrained eye and trained spatial frequency, open squares show the data for the untrained eye and untrained spatial frequency and filled squares show the data for the trained eye and untrained spatial frequency. Only pre- and post-training measurements were taken for the remaining conditions (e.g., untrained spatial frequency, untrained, other eye). Observer LM is normally sighted while observers CW and CR are anisometropic amblyopes. It can be seen that for observer LM there is only slight improvement using this training method (she goes from a sensitivity of 55.5 to 61.9, an 11.5% increase). Observer CW shows no improvement (84.7 to 81.0, a 4.0% decrease). Observer CR does show improvement between pre- and post-training scores (43.4 to 84.3, a 42.6% increase), however this improvement is not consistent over training days. The contrast required to detect the sinusoidal stimulus 71% of the time did not substantially change over the six training days for two of these three observers.

Figure 8 presents data for the same three observers showing the percent of improvement as a function of the task. Open bars

represent data for the trained eye. The untrained eye is shown by filled bars. The data for each observer will be discussed in turn.

Observer LM (top panel) is a 38 year old normal female trained on 12.0 cpd using the staircase method. Contrast sensitivity measured on the VCTS chart shows the greatest improvement (47.5%) at the trained spatial frequency. CRT (computer) measures show a small amount of improvement for the trained eye at both 3.0 (12.8%) and 12.0 (11.5%) cpd. Minimal improvement is seen in the acuity of the trained eye (5.9%). Performance measures reveal a 37.2% improvement on the discrimination of letters in the trained eye as would be expected since the fundamental frequency of the letters is 12.0 cpd.

Observer CW (center panel) is a 14 year old male anisometropic amblyope trained at 3.0 cpd using the staircase method. He shows very large improvement at all spatial frequencies for VCTS measurements in his trained eye only. In his case it appears that the mere use of the eye has improved his contrast sensitivity to all spatial frequencies. He also shows substantial improvement in the acuity of his trained eye. Performance measures show the greatest improvement in the discrimination of faces (66.9%) as would be expected since face targets were highly represented by 3.0 cpd components.

Observer CR (bottom panel) is a 26 year old female amblyope trained on 12.0 cpd using the staircase method. She did not show any improvement at the trained spatial frequency but did have large improvement at the other spatial frequencies on the VCTS chart. She shows 94.2% improvement at 12.0 cpd in the trained eye on the CRT. She has shown substantial improvement (96.2%) in her trained eye for the discrimination of letters as would be expected for an individual trained at 12.0 cpd.

Method of Constant Stimuli

Figure 9 presents the percent correct data for observers LH and SK. Both are normally sighted individuals. Each data point represents the average of at least 500 two-alternative contrast detection decisions. It can be seen that there is an increase in the percent of responses which are correct over the training days. For observer LH percent correct scores change from 60.5% to 68.5% (a 29.4% increase), observer SK from 68.6 to 94.7 (a 38.1% increase).

Figure 10 presents data for the same two observers showing the amount of improvement seen over the four pre- and post-training tasks. Observer LH is a 62 year old female trained at 3.0 cpd. She demonstrates 29.4% selective improvement for the trained eye at 3.0 cpd and surrounding frequencies (1.5 cpd = 13.8%, 6.0 cpd = 13.5% improvement) using the VCTS charts. CRT measurements show selective improvement at both 3.0 (13.2%) and 12.0 (35.5%) cpd. She

demonstrates no change in the acuity of either eye. She shows slight improvement in the discrimination of faces (6.2%) and the detection of letters (12.1%).

Observer SK is a 50 year old normal who was trained at 3.0 cpd using the method of constant stimuli. She shows little improvement on the VCTS in her trained eye, but on the CRT shows 38.1% and 39.3% improvement for 3.0 and 12.0 cpd in the trained eye, respectively. Her acuity showed no improvement. She shows 36.1% improvement in the detection of signs and 71.7% and 36.5% improvement in the detection and discrimination of faces, respectively.

Figure 11 presents the percent correct data for observers RB and DT. Both are normally sighted individuals. There is a small increase in the percent of responses which are correct over the training days. For observer RB the increase is from 75.8% to 91.4% (an increase of 62.3%), and observer DT from 75.7% to 84.1% (a 37.5% increase).

Figure 12 presents the individual percent improvement data for observers RB and DT. RB is a 42 year old female trained on 12.0 cpd. She demonstrates the greatest improvement in contrast sensitivity on the VCTS and CRT tasks for the trained spatial frequency (62.3% and 20.5%, respectively). She shows a slight improvement in the acuity of both eyes (11%). Performance measures reveal the greatest improvement for the detection of faces (33.9%) and letters (34.7%).

Observer DT is a 46 year old trained on 12.0 cpd. She shows the greatest amount of improvement at 1.5 cpd (71.4%) and 18.0 cpd (62.5%) for the VCTS and at 12.0 cpd (11.9%) on the CRT. Her acuity however is not altered. She also shows improvement in the detection (21.4%) and discrimination (35.7%) of faces and the discrimination (14.5%) of letters.

Figure 13 presents the percent correct data for observers MS, LS and MW. All three observers are anisometropic amblyopes trained using the method of constant stimuli. Observers MS and LS show some improvement in the trained eye and spatial frequency conditions, namely from 78.1% to 89.8% (14.5% increase) and 78.2% to 94.8% (a 16.5% increase) respectively, while observer MW shows only 1.5% improvement. A possible explanation for the lack of improvement seen in observer MW may have to do with the severity of her amblyopic eye as indicated by an ophthalmological exam.

Figure 14 shows the percent improvement scores for the three amblyopes trained using the method of constant stimuli. Observer MS (top panel) was trained at 3.0 cpd and shows substantial improvement in this (203%) and the surrounding two spatial frequencies (1.5 cpd = 242% and 6.0 cpd = 352%) using the VCTS chart, however on the CRT display he shows the greatest improvement

(45.2%) at 12.0 cpd in the untrained eye. A 33% improvement in acuity in his trained eye is seen. Performance measures show the greatest improvement (42%) for the discrimination of faces as would be expected for an observer trained at 3.0 cpd.

The center panel presents the percent improvement scores for observer LS, a 42 year old female amblyope trained at 12.0 cpd. She shows selective improvement at the trained spatial frequency on the CRT task in both the untrained (23%) and trained (21.2%) eyes. She shows substantial improvement on the detection (85.6%) and discrimination of faces (38.3%) and on the detection (29.4%) and discrimination of letters (24.4%).

Observer MW is a 43 year old female with severe anisometropic amblyopia trained at 12.0 cpd. She has shown significant improvement in VCTS scores for 1.5 cpd (566%), 3.0 cpd (1000%) and 12.0 cpd (400%). Very little improvement is seen in the other tasks except for the detection of letters where she shows 24.6% improvement.

General Findings (Results and Discussion: Groups A and B)

Separate repeated measures ANOVAs were performed on the normal observers percent change data to determine general trends in the data for each of the different tasks required of the observers from Groups A and B.

VCTS chart results were analyzed for normal observers in a method x trained spatial frequency x trained eye x task spatial frequency ANOVA. The results of this analysis revealed no significant main effects or interactions apparently due to the inability of the chart to measure further increases in contrast sensitivity of the initially high sensitivity in these normal observers. All but one observer showed very high chart scores for all spatial frequencies. This resulted in little room for improvement to be measured because of the limited number of discrete steps in contrast on the chart. Figures 15-19 present the contrast sensitivity data as measured on the VCTS chart for normal observers in Group B. Comparable information for observers in the Group A pilot experiment are shown in Figures 5, 6, 20-23.

A four-way ANOVA was performed on the CRT data. This analysis revealed a main effect of the trained vs. untrained eye with the trained eye showing the most improvement after training ($F(1,7) = 19.65$, $p < 0.01$). There was no difference in improvement between the observers trained on 3.0 or 12.0 cpd ($F(1,7) = 0.83$, $p > 0.05$). Although there was no difference between the two methods of training ($F(1,7) = 0.00$, $p > 0.05$) in the analysis, there was a significant spatial frequency x method interaction ($F(1,7) = 7.13$, $p < 0.05$). The staircase method showed an average of 16.9% and 16.3% improvement at 3.0 and 12.0 cpd, respectively, while the method of constant stimuli showed improvement of 23.8% and 10.2%

for 3.0 and 12.0 cpd. Thus, the method of constant stimuli resulted in exceeding the amount of improvement expected for normal observers (i.e., at least 20% at 3.0 cpd and 4% at 12.0 cpd).

ANOVA on the acuity scores of normal observers in the staircase and method of constant stimuli paradigms revealed that most improvement was only seen in acuity for observers trained at 12.0 cpd using the staircase method as revealed by a significant three-way interaction between trained eye, trained spatial frequency and method ($F(1,6) = 98.89, p < 0.001$). These results support the fact that both 12.0 cpd detection and acuity tasks require fine detail discriminations.

Analysis of the performance data revealed a significant three-way interaction between the stimulus, trained/untrained eye and detection/discrimination ($F(1,7) = 9.15, p < 0.05$). Thus the most improvement was seen in the trained eye for both face and letter discrimination, and also for the discrimination of faces in the untrained eye. There was no significant increase in the detection or discrimination of highway signs. The rate at which the signs were gradually increased in contrast may explain this lack of a training effect. Several observers commented that the stimuli could not initially be seen for over one minute. If the observer allowed his attention to wander, when the stimulus came into view their threshold value may not be accurate. Future research will initially have the contrast increment rate faster, then slowly increase the contrast increment rate as the contrast nears detection threshold.

Because there were five amblyopic observers in the four training conditions (2 spatial frequencies x 2 methods) pre- vs. post-training data were analyzed using T-tests on related means for each of the different tasks required of the observers.

Analysis of the VCTS data for the amblyopes revealed that the amount of improvement in the trained eye was statistically significant ($t = 4.1446, df = 3, p < 0.05$) but it was not in the untrained eye ($t = 0.345, df = 3, p > 0.05$). The amount of improvement for observers trained on 12.0 cpd was significant at 3.0 cpd ($t = 6.32, df = 1, p < 0.05$) and at 6.0 cpd ($t = 77.78, df = 1, p < 0.01$) in the trained eye. Observers trained at 3.0 cpd showed significant improvement at 6.0 cpd in the trained eye ($t = 11.39, df = 1, p < 0.05$). Thus, improvement on the VCTS did occur in the trained eye of amblyopes, however this improvement was not selective to the trained spatial frequency.

A significant amount of improvement was seen on the CRT in the trained and untrained eyes of the amblyopes at 12.0 cpd for observers trained using the method of constant stimuli ($t = 10.1, df = 1, p < 0.05$; $t = 12.16, df = 1, p < 0.05$). The analysis suggested that there was not a significant improvement at the trained spatial frequency although the figures show a substantial improvement (an average increase of 28.9%) in the trained eye.

Because there were only two observers trained at 3.0 cpd and three at 12.0 cpd, the amount of variance between the degree of improvement on the CRT resulted in insignificant improvement seen at the trained spatial frequency. In summary, improvement was observed on the CRT in the trained eye of amblyopes. When observers were trained at 12.0 cpd, training was selective to the trained spatial frequency. This result was not seen for the VCTS. One explanation for this could be that observers were given incentive pay for correct answers on the CRT task but not on the VCTS.

Analysis of the pre- vs. post-training acuity scores revealed a significant improvement in the trained eye when amblyopic observers were trained at 12.0 cpd ($t = 21.12$, $df = 1$, $p < 0.05$), showing an average of 21% improvement in acuity scores. This is an expected result since both acuity and high spatial frequency contrast detection require the discrimination of fine detail.

Amblyopic observers also showed significant improvement in the detection of signs in the amblyopic trained eye when trained at 12.0 cpd ($t = 12.21$, $df = 1$, $p < 0.05$). The amount of improvement for the detection or discrimination of letters or faces was not dependent on whether the observer was trained at 3.0 or 12.0 cpd. However, the staircase method did lead to significant improvement in the detection of letters in the trained eye ($t = 24.25$, $df = 1$, $p < 0.05$).

Individual Differences

Large individual differences in contrast sensitivity were found before training. These differences may be seen in Table 1. Many normal observers showed very high initial contrast sensitivity, whereas others showed lower sensitivity. The pre-training CRT contrast sensitivity scores in the three high sensitive observers trained at 3.0 cpd were 217, 210 and 149.3. The pre-training CRT scores in the three lower sensitive observers was 68.6, 100 and 100. Individual differences were also seen for observers trained at 12.0 cpd. The pre-training CRT contrast sensitivity scores for three high sensitive normal observers trained at 12.0 cpd were 80, 79.3 and 75.7 and for two low sensitive observers were 55.5 and 60.7. Although observers can be ranked as being either low or high sensitive there are still large individual differences within these categories.

Individual differences in contrast sensitivity were also present after training. Those observers trained at 3.0 cpd who were initially ranked as high sensitive observers showed contrast sensitivity scores after training of 245.2, 283.9 and 111.5. The lower sensitive observers showed post-training contrast sensitivity scores of 94.7, 149.3 and 177.4. The post-training CRT contrast sensitivity scores for the three observers who were ranked as high sensitive were 93.9, 100.2 and 93. The two low sensitive observers showed post-training scores of 61.9 and 102.9. Thus, observers

showed different amounts of improvement in contrast sensitivity after training. These data suggest that an individual's contrast sensitivity before training does not predict contrast sensitivity after training.

Large individual differences may also be seen in the amblyopic group. Contrast sensitivity values for the two amblyopic observers trained at 3.0 cpd were 43.4 and 47.8. These scores are lower than the normal "low sensitive" contrast sensitivity scores. Post-training scores for these same two amblyopic observers were 49.7 and 81.1. The pre-training contrast sensitivity scores for the three amblyopic observers trained at 12.0 cpd were 2.9, 32.6 and 83.4, post-training scores were 2.9, 37.9 and 119.1. These data show large individual differences in the pre- and post-training contrast sensitivity for amblyopic observers trained at both 3.0 and 12.0 cpd.

There were also large individual differences on the VCTS scores (Table 1). The pre-training VCTS contrast sensitivity scores in the same high sensitive, normal observers discussed above who were trained at 3.0 cpd were 170.0, 175.0 and 158.3 and in the low sensitive observers were 170.0, 93 and 158.3. The post-training VCTS contrast sensitivity scores in the same high sensitive observers were 220.0, 220.0 and 170.0 and in the low sensitive observers were 203.3, 186.7 and 203.3. The pre-training VCTS contrast sensitivity scores for high sensitive normal observers trained at 12.0 cpd were 127.7, 127.7 and 112.7 and for low sensitive observers were 100.3 and 77. Post-training VCTS contrast sensitivity scores in the high sensitive observers trained at 12.0 cpd were 155, 140 and 155 and for low sensitive observers were 125 and 140. These data provide three findings: high or low contrast sensitivity from the CRT measurements did not necessarily relate to high or low contrast sensitivity from the VCTS, sensitivity before training did not directly relate to post-training scores and individual differences were also seen on the VCTS chart in pre- and post-training scores.

Individual differences were also seen for VCTS scores before and after training for amblyopic observers (Table 2). Pre-training VCTS scores for both amblyopic observers trained at 3.0 cpd were 37.3 and 37.3. Post-training VCTS contrast sensitivity scores in these amblyopic observers were 113.3 and 85. The pre-training contrast sensitivity scores for the three amblyopic observers trained at 12.0 cpd were 1.0, 66.0 and 125.0, post-training scores were 5.0, 81.7 and 115.3. These data show large individual differences in pre- and post-training scores for these amblyopes.

These data indicate that the percent improvement was greater in those normal observers having lower initial sensitivity. Averaged percent improvement scores on the VCTS for the high sensitive observers were 21.9% and for the low sensitive observers were 52.45%. Averaged percent improvement scores for the high and

low sensitive observers on the CRT were 15.13% and 46.11%, respectively. Thus, although improvement was seen in both low and high sensitive observers, greater improvement was seen in the low sensitive group. This finding is further supported by percent improvement scores for amblyopes on the VCTS of 133.3%, an even larger increase than found in the low sensitive normal group. There did not appear to be any general trend in the rate of improvement for either low sensitive or high sensitive observers, however the rate and relative magnitude of training for high and low sensitive observers will be further explored in Phase II of this project.

There also were large individual differences on percent improvement scores for the performance tasks. There was a general trend for the observers trained at 3.0 cpd and 12.0 cpd to show the most improvement on the detection and discrimination of faces. There was no relationship found for the amount of improvement between the observers classified in the low or high contrast sensitive groups as discussed above.

These contrast sensitivity and performance data show considerable individual differences in training. It is not clear why some observers showed substantial improvement while others did not. Most likely there are several factors that will effect the rate and absolute magnitude of training. Some of these explanations may be physiological and some cognitive. Some likely explanations are discussed below.

One possible explanation for the large individual differences in training could be due to afterimages. Some observers were noted to not follow instructions as well as others. As a part of the instructions, observers were asked to allow their eyes to wander over the display screen in order to prevent the formation of an afterimage of the circular screen (mean luminance was 40 cd/m²). If some observers fixated more than others, the interfering effects of the afterimage could effect performance and therefore the effects of training. To limit the effect of afterimages and test this possibility, future research will lower the mean luminance level of the display screen.

Another possible explanation for the large individual differences seen in the data could be that some observers monitor different sets of visual mechanisms not related to the mechanisms being trained during the course of the experiment. According to Graham (1989), some individuals may be unable to selectively monitor a limited number of mechanisms. Attending only to mechanisms which are responsive to the stimulus would be the optimal strategy in this experiment since there would be no uncertainty about what spatial frequency stimulus would be presented in a block of trials. Thus, some observers may monitor all mechanisms equally thereby decreasing the effectiveness of the training procedure.

This selective monitoring hypothesis is supported by the work of Ginsburg et al. (1980) who found that the perceived contrast of a square-wave grating is directly comparable to the magnitude of its fundamental frequency component. These data imply that the visual system can select different spatial frequency components for the perception of different properties of the stimulus. Ginsburg (1978) has proposed that visual perceptions are formed by hierarchical filtering of the objects. The spatial properties of an object stimulate different spatial filters, or mechanisms, which provide part of the information about the object that can be attended to independently of the other information. Thus, the ability to recognize a complex form (such as a face, even though the face may differ from other faces) may be the result of attending the the information in one or more visual mechanisms. Individual capabilities for attending to these visual mechanisms may relate to training effectiveness.

One possible way to help predict which observers monitor a select number of mechanisms versus which observers monitor all the spatial mechanisms simultaneously could be to measure performance on an embedded figures task. In a typical embedded figures test, the observer is shown several isolated figures and a complex scene containing one of these figures. The task is to identify which figure is embedded in the complex scene. Embedded figures tasks can separate individuals according to their spatial ability (Ward, 1984). Observers who have difficulty with this kind of task are called field dependent. Field independent observers do not have difficulty with embedded figures tasks. It is possible that field dependent observers simultaneously monitor all spatial channels, while field independent observers monitor a select number of mechanisms. A possible way to test the hypothesis that the contrast sensitivity training procedure would be more effective in field independent observers would be to first measure performance on an embedded figures task and then see if the effects of training are greater in the field independent group of observers. This research could lead to valuable information about which observers would benefit the most from contrast sensitivity training procedures based on their performance on an embedded figures task. This hypothesis will be researched further and tested in Phase II research.

Some normal and amblyopic observers showed improvement in contrast sensitivity and performance measures in the untrained eye. That training was not always specific to the trained eye suggests that the effects of training are either post-chiasmic or are due to general learning strategies. It is possible that observers developed a cognitive strategy over the course of training and this strategy extended to measurements taken on the untrained eye. Since 5 of 11 normal observers and 3 of 5 amblyopic observers did not show spatial frequency selective training supports this hypothesis, however, more data is needed to reach a stronger conclusion.

Another possible explanation of why training was also seen in the untrained eye of some observers is that binocularly driven spatial mechanisms may have been effected by contrast sensitivity training. The usual test of the binocularity of a cell is whether the cell can be driven by either eye alone. Research suggests that spatial mechanisms may be differentially sensitive to inputs from the two eyes (Arditi et al., 1981). If differential sensitivity of binocularly driven neurons can explain these results, then training observers only in the dominant eye should produce maximal improvement. These hypotheses will be explored further in Phase II research.

Conclusions

The contrast sensitivity at two spatial frequencies, 3.0 and 12.0 cpd, were trained using two forced-choice techniques. It was predicted that if the present training techniques were successful in increasing contrast sensitivity, normal observers should show at least 20% improvement at 3.0 cpd and 4% improvement at 12.0 cpd. The average results indicate that normal observers trained on 3.0 cpd using the staircase method show 64.6% and 58.7% improvement on the VCTS and CRT, respectively. The percent improvement for observers trained at 3.0 cpd using the method of constant stimuli met this criterion for the VCTS (20.5%) but did not on the CRT (15.3%). Observers trained at 12.0 cpd using the staircase method found 34.45% improvement on the VCTS and 15.15% improvement on the CRT. Those observers trained at 12.0 cpd using the method of constant stimuli found 36.5% improvement on the VCTS and 39.4% improvement on the CRT. Thus, for normal observers, both the staircase and method of constant stimuli were effective procedures for improving performance on the VCTS and CRT (except for CRT scores for observers trained at 3.0 cpd using the method of constant stimuli).

Amblyopes were predicted to show at least 30% improvement at 3.0 cpd and 90% improvement at 12.0 cpd. The averaged results indicate that amblyopic observers trained at 3.0 cpd using the staircase method show 127.8% and 69.5% improvement on the VCTS and CRT, respectively. The percent improvement for the observer trained at 3.0 cpd using the method of constant stimuli met this criterion for the VCTS (203.7%) but did not on the CRT (14.5%). The amblyopes trained at 12.0 cpd using the method of constant stimuli showed substantial improvement and this improvement in contrast sensitivity was only seen on the VCTS (171.4%) not the CRT (9%). There was no improvement seen on the VCTS and 42.6% improvement seen on the CRT for amblyopic observers trained using the staircase method. Ginsburg et al. (1985) demonstrated a strong relationship between contrast sensitivity scores on the VCTS with CRT measures in a large population study. Based on this finding, VCTS and CRT percent improvement scores should be similar. It is not clear why a greater amount of improvement was seen on the VCTS chart than on

the CRT. One possible reason could be the small sample size tested in the current experiment.

Based on previous contrast sensitivity related performance results and similar results reported here, a 25% increase in present performance scores were considered significant. The averaged results indicate that normal observers trained at 3.0 cpd using the staircase method showed substantial improvement in the discrimination of both faces and letters (54.2% and 45.65%, respectively). The detection of faces and letters using either training technique did not meet the 25% improvement criterion. The percent improvement for the detection of faces for the staircase and method of constant stimuli were 14.3% and 12.9%, respectively for those trained at 3.0 cpd and 3.1% and 22% for those trained at 12.0 cpd. The percent improvement for the detection of letters for the staircase and method of constant stimuli were 4.8% and 12.9%, respectively for those trained at 3.0 cpd and 0.0% and 4.6% for those trained at 12.0 cpd. Thus, only the discrimination of faces improved the by criterion amount.

Improvement in performance was greater for amblyopic observers than for normal observers. Amblyopic observers trained at 3.0 cpd using either training technique showed substantial improvement in the detection (44.41% for staircase and 25.5% for method of constant stimuli) and discrimination (66.99% for staircase and 42% for method of constant stimuli) of faces. Amblyopes trained at 12.0 cpd showed substantial improvement in the detection of letters (27%) using the method of constant stimuli and in the discrimination of letters (96.2%) using the staircase method. For amblyopes, both facial and letter detection and discrimination improved by the criterion amount.

The results of this pilot work suggests that two-alternative forced-choice methods are effective training procedures in both normal and amblyopic observers. The staircase method appears to be superior of the two forced-choice techniques. The staircase method resulted in improved contrast sensitivity scores in three of four observers on the VCTS (58.6%) and four of four observers on the CRT (54.3%). Because improvement was seen on both the VCTS chart and CRT suggests that the VCTS chart can be used to monitor the progression of training. The staircase method resulted in an average of 55.3% improved performance in the discrimination of faces for both normal observers trained at 3.0 cpd. This method resulted in an average of 18.6% improved performance in the discrimination of letters for those normal observers trained at 12.0 cpd. No specific trends in improvement were seen for any observers on the detection or discrimination of signs, likely due to methodological problems as discussed above.

The two amblyopic observers trained using the staircase method showed improved contrast sensitivity to all spatial frequencies on the VCTS. One of these observers showed 94.2% improvement in

contrast sensitivity which was selective to the trained spatial frequency on the CRT. These amblyopic observers showed improved performance on facial discrimination when trained at 3.0 cpd (66.9%) and improved letter discrimination when trained at 12.0 cpd (96.2%).

Amblyopic and normal observers showed similar contrast sensitivity increases in the percent improvement on the CRT after training. Normal observers showed an average of 29.7% improvement in contrast sensitivity scores on the CRT at 3.0 and 12.0 cpd while amblyopes showed an average of 31.1% improvement. Amblyopes showed greater increases in the detection and discrimination of real-world targets than did normal observers. The average amount of improvement in the detection of signs, faces and letters was 5.8% for normals and 16.0% for amblyopes. The average amount of improvement in the discrimination of these targets after training was 12.7% for normals and 18.5% for amblyopes.

The results of this Phase I research suggest that large increases in contrast sensitivity due to vision training are possible in some normal and amblyopic observers. These increases in contrast sensitivity ranged from 11.5% to 69.2% in normals and from 1.5% to 69.5% in amblyopes. There were also large individual differences in the amount of improvement on performance tasks. Normal observers showed increases in the detection or discrimination of real-world targets from no improvement to 81.2% improvement. Amblyopes showed increases in performance from no improvement to 96.2% improvement. These data raise the very important research issues concerning individual differences on the effectiveness of contrast sensitivity training in normal and amblyopic observers and will be further explored in Phase II of this project.

The specific Phase I objectives were met during this research period. Additional objectives furthering this research are outlined in a Phase II proposal, which is submitted under separate cover.

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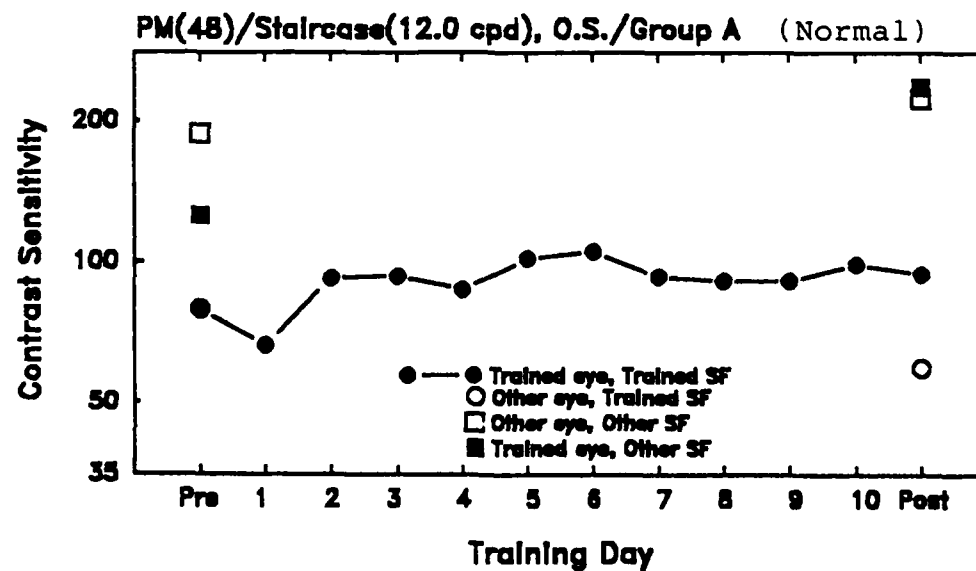
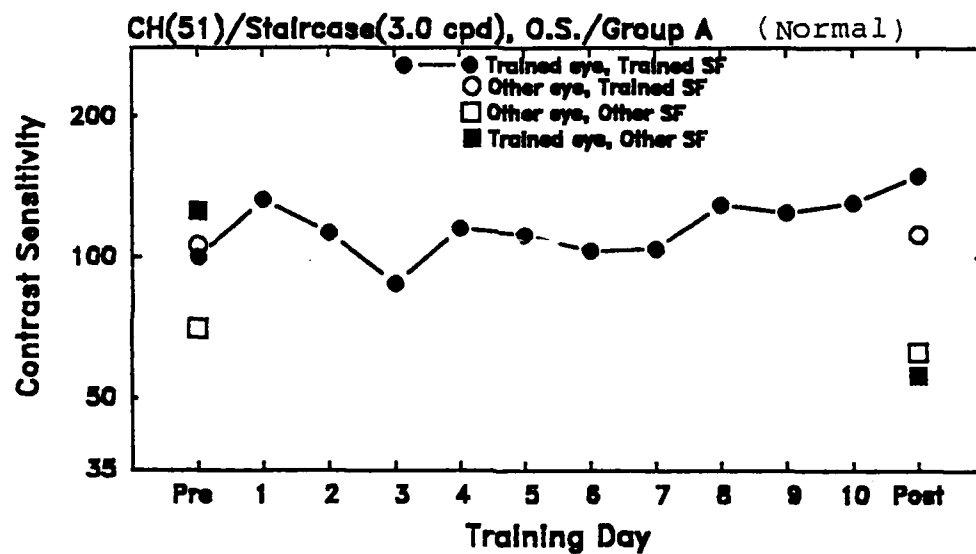
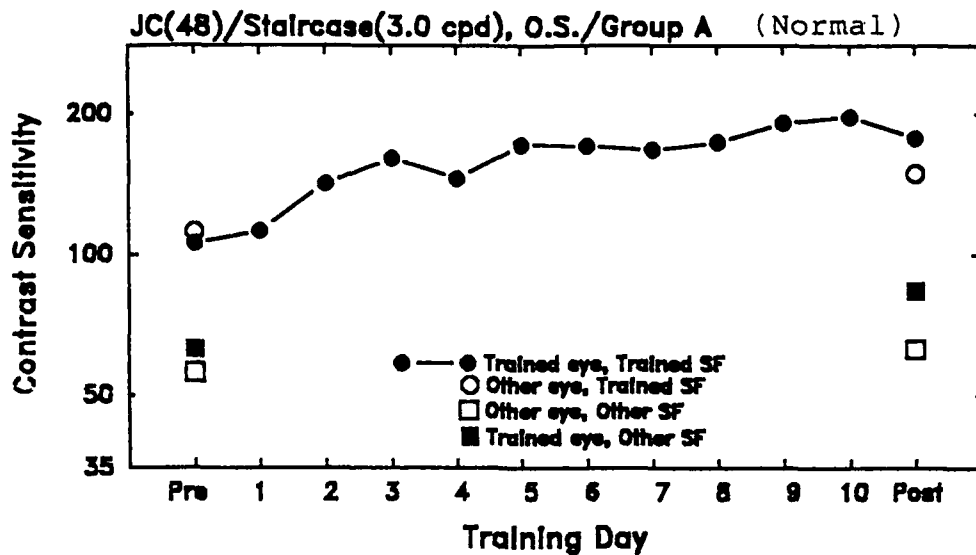


Figure 1

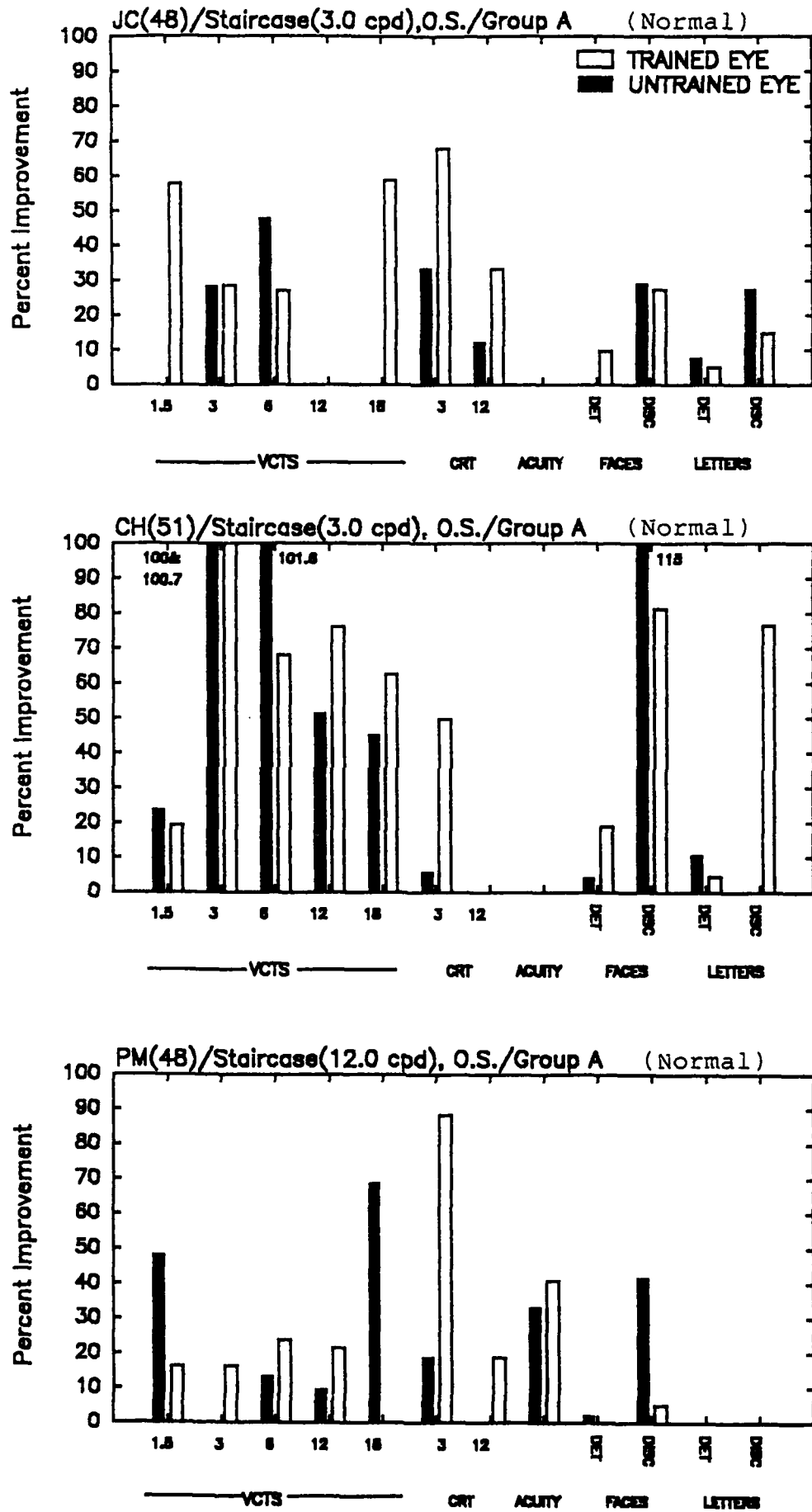


Figure 2

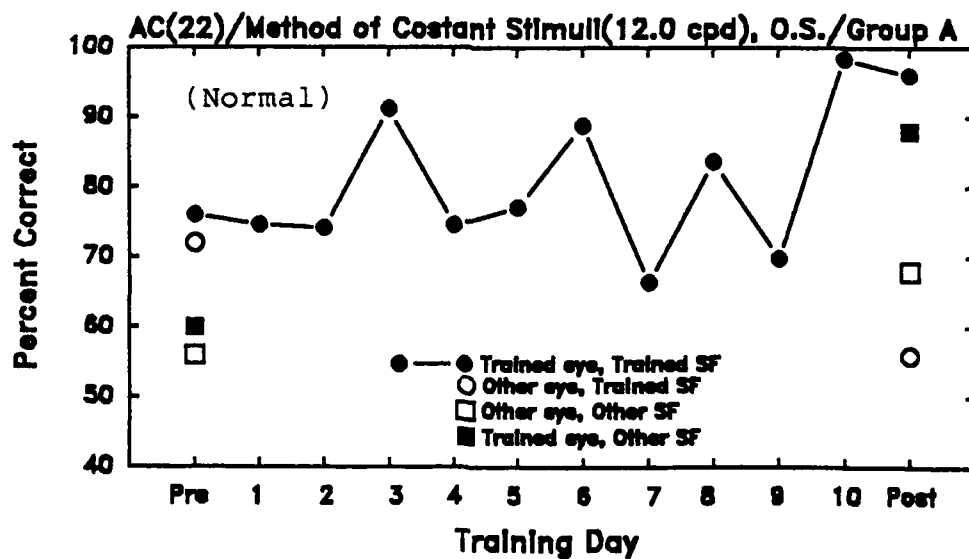
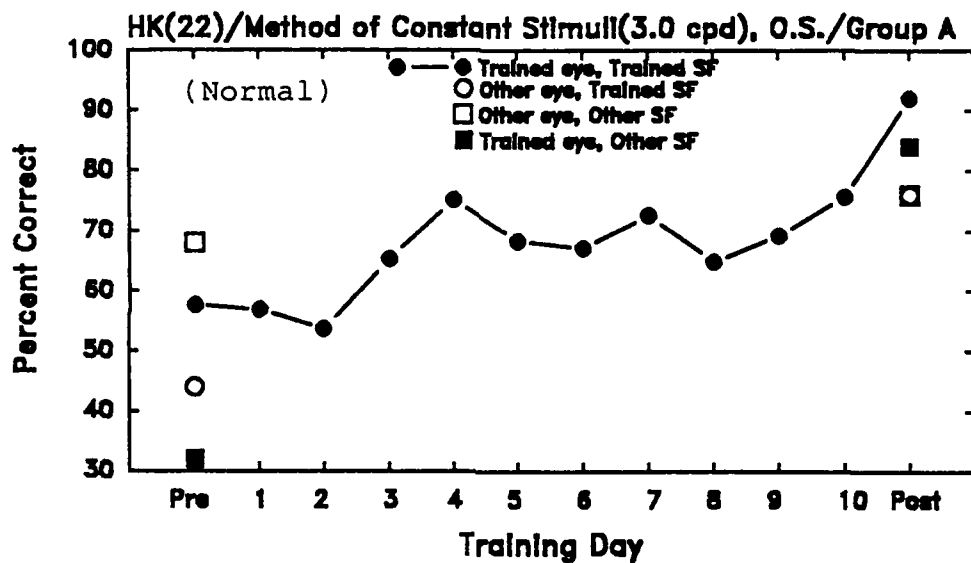
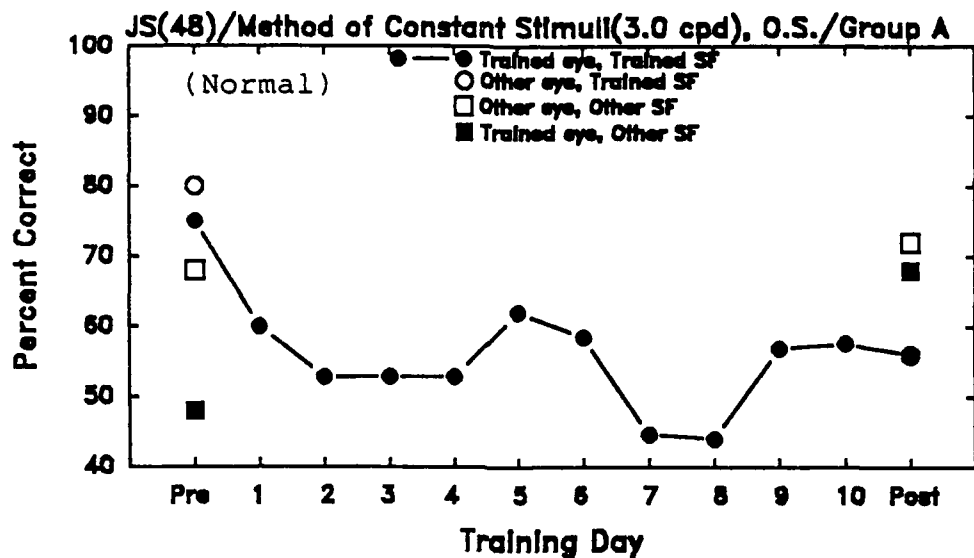


Figure 3

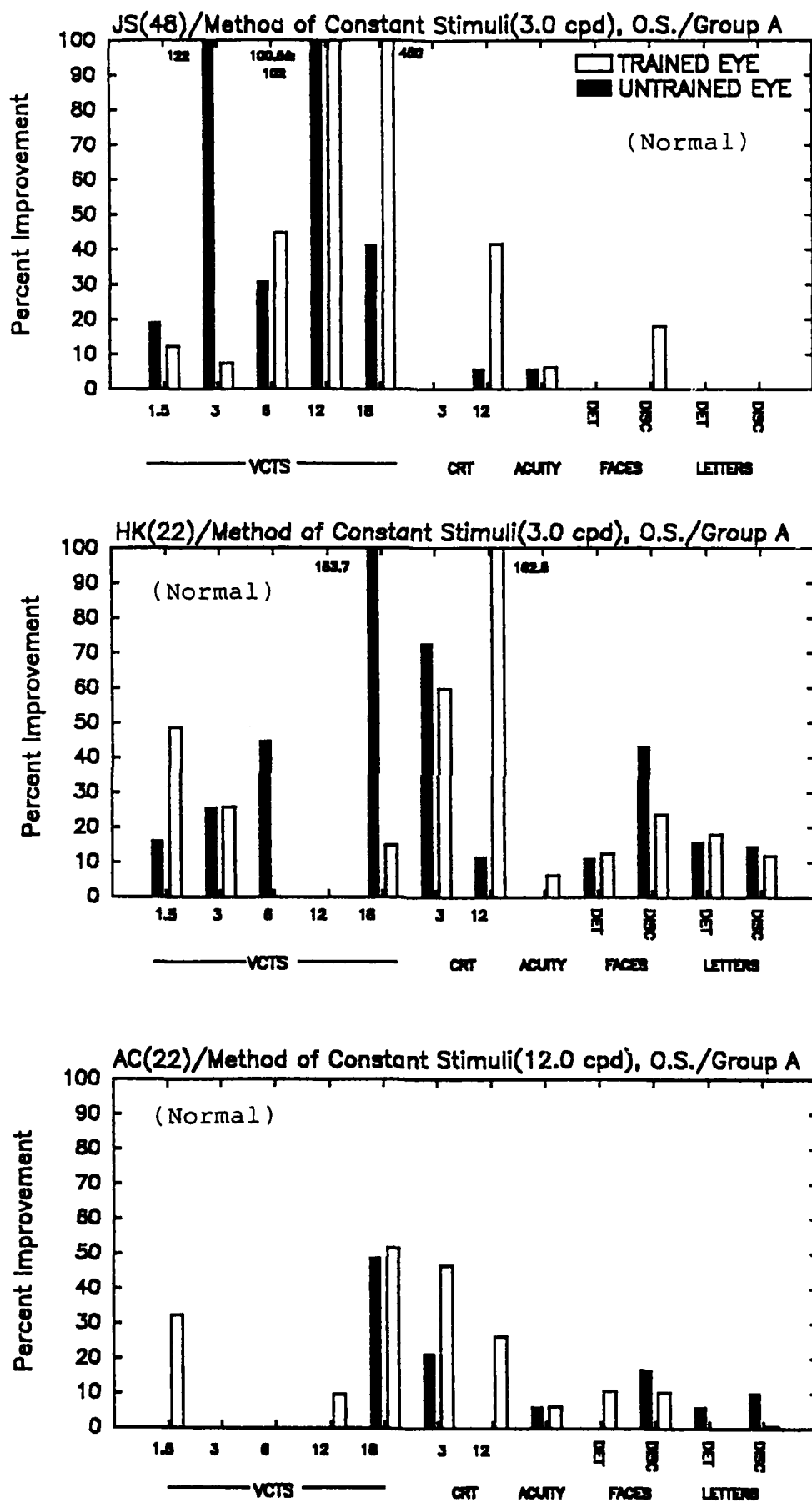
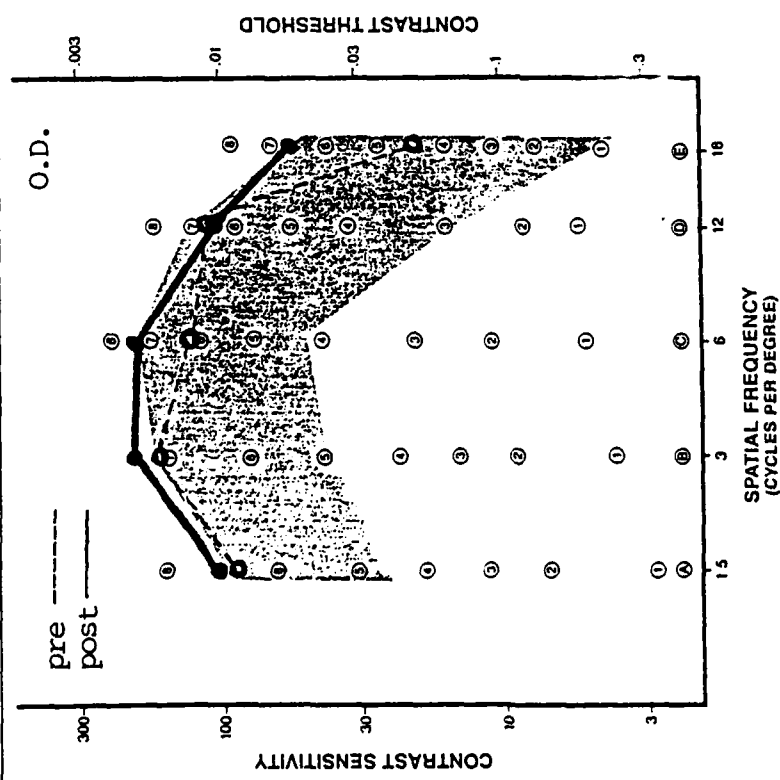


Figure 4



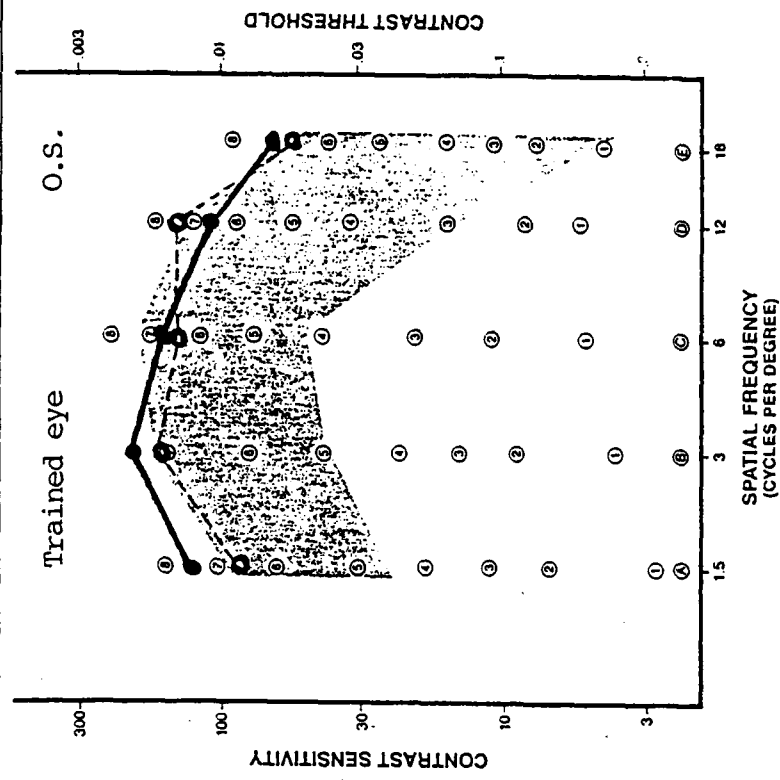
OBSERVER NAME HK (22) DATE 1990
 VCTS* SYSTEM USED _____ TESTING DISTANCE _____
 COMMENTS: trained on 3 cpd
normal

Tested by: _____

The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the Instruction Booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due strictly to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

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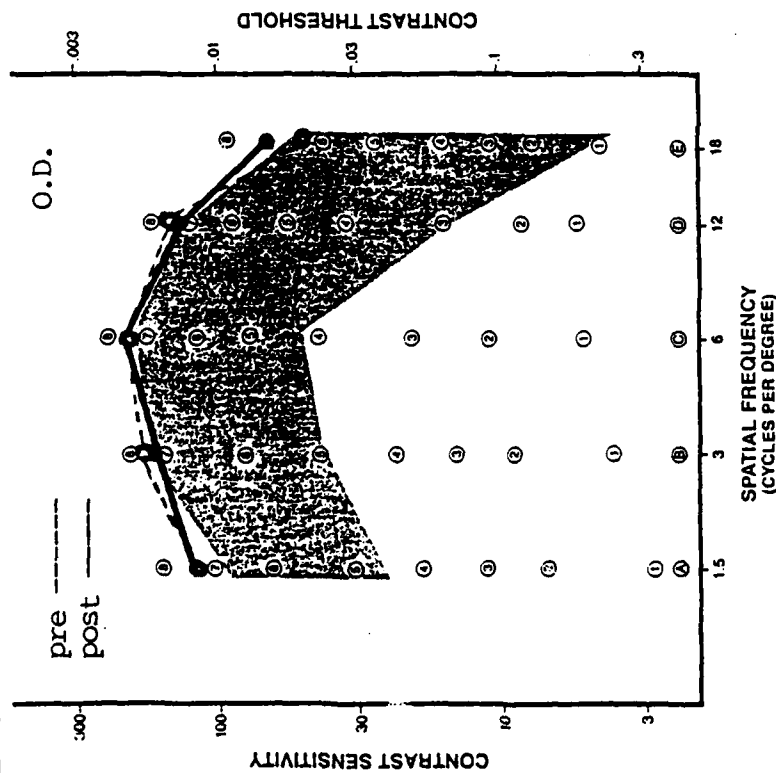
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 VCTS* SYSTEM USED _____ TESTING DISTANCE _____
 COMMENTS: _____

Tested by: _____

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Figure 5

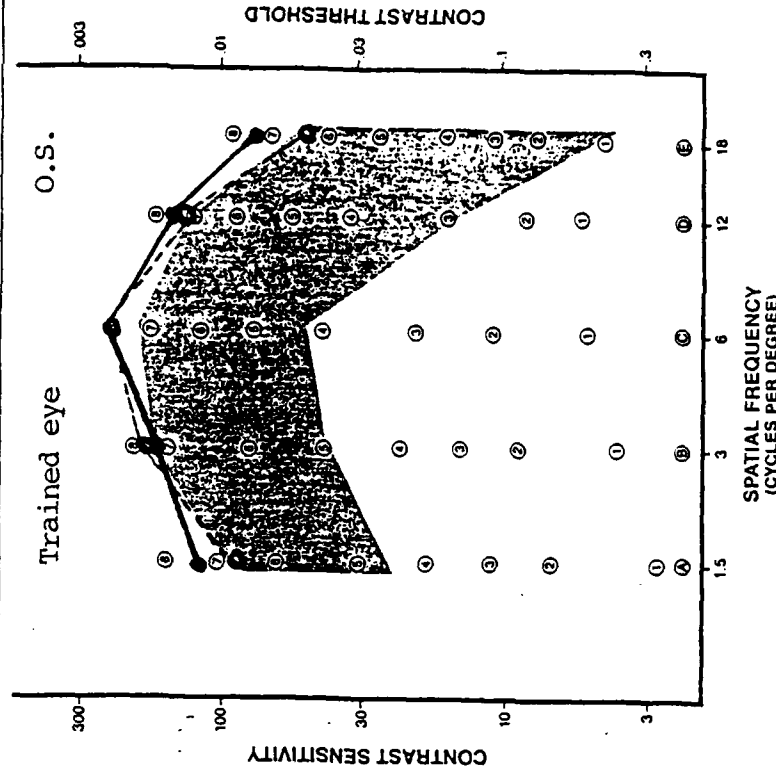


OBSERVER NAME AC (22) DATE 1990
 VCTS® SYSTEM USED _____ TESTING DISTANCE _____
 COMMENTS: trained on 12cpd
normal

Tested by: _____

The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the Instruction Booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due strictly to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

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OBSERVER NAME _____ DATE _____
 VCTS® SYSTEM USED _____ TESTING DISTANCE _____
 COMMENTS: _____

Tested by: _____

The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the Instruction Booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due strictly to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

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Figure 6

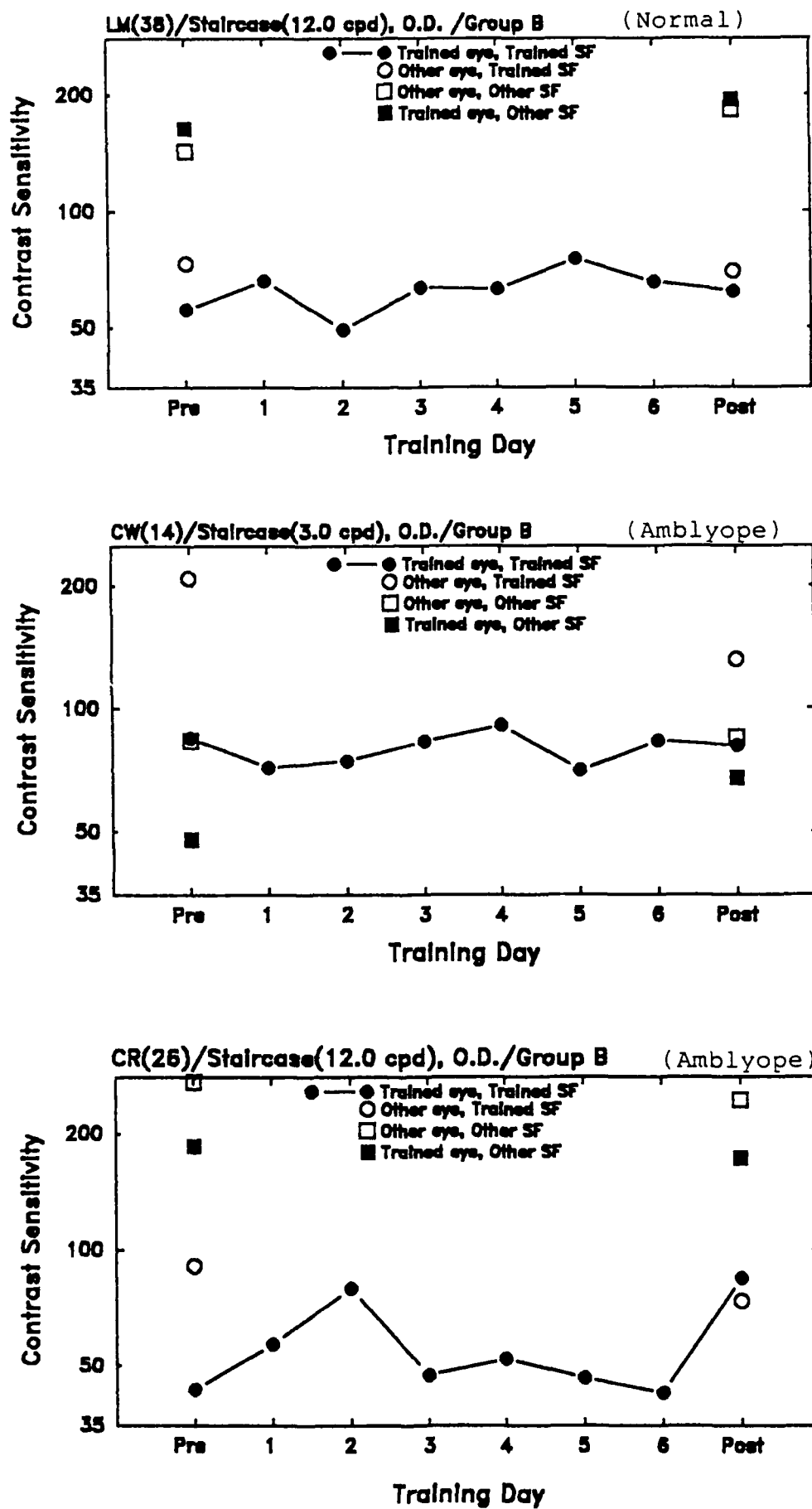


Figure 7

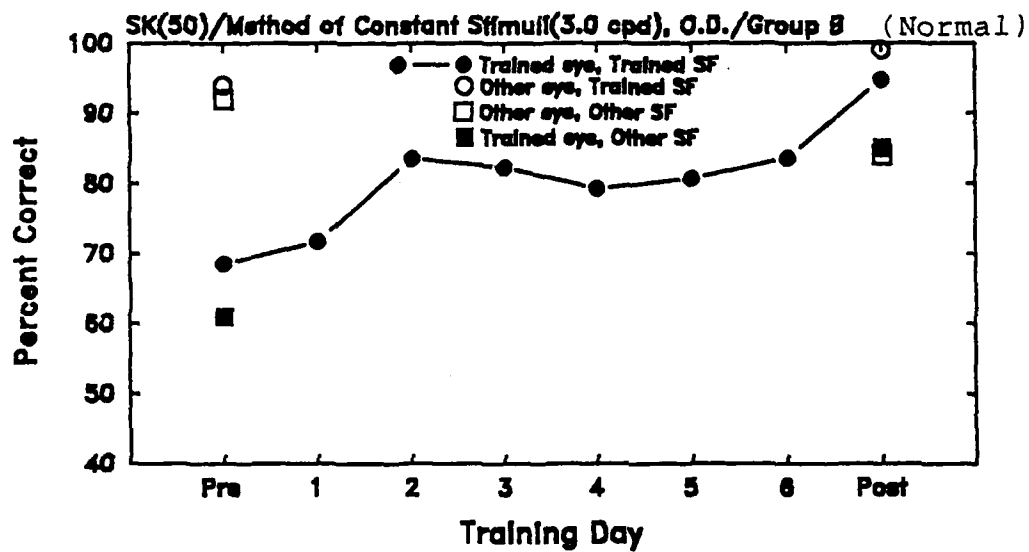
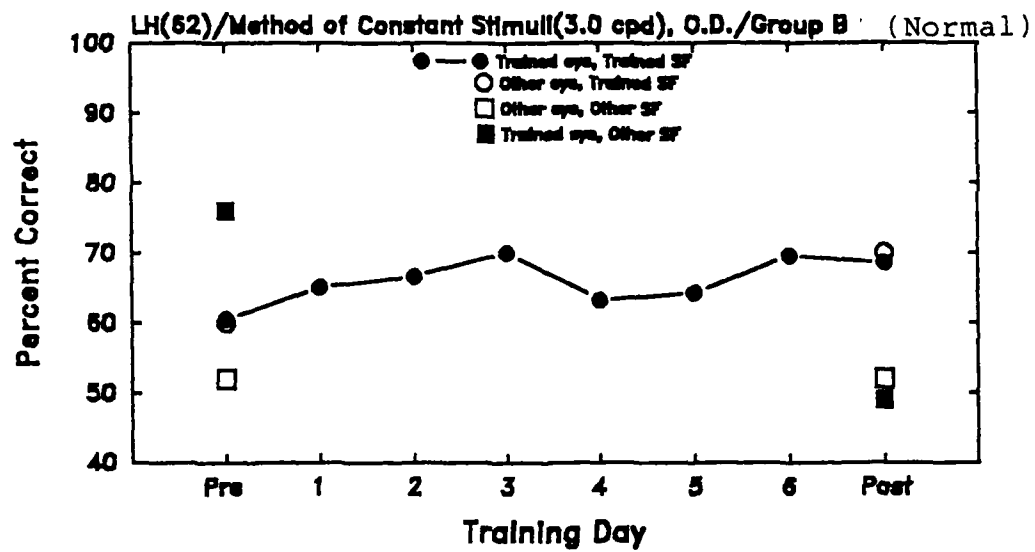


Figure 9

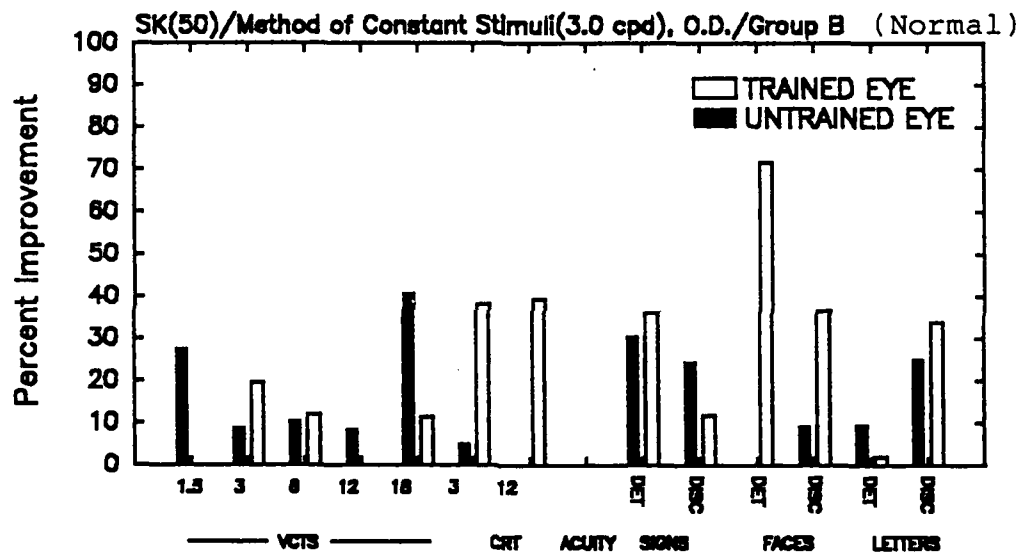
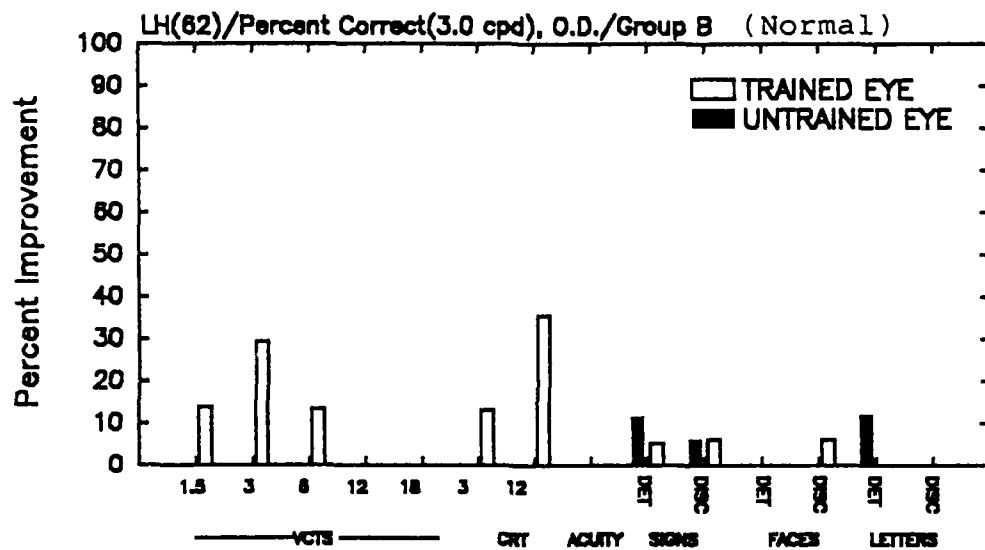


Figure 10

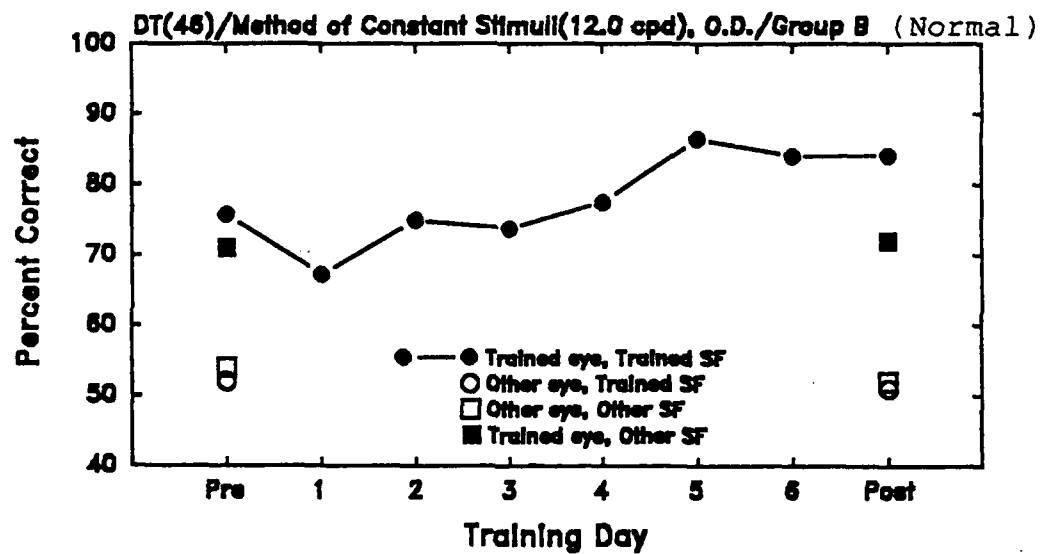
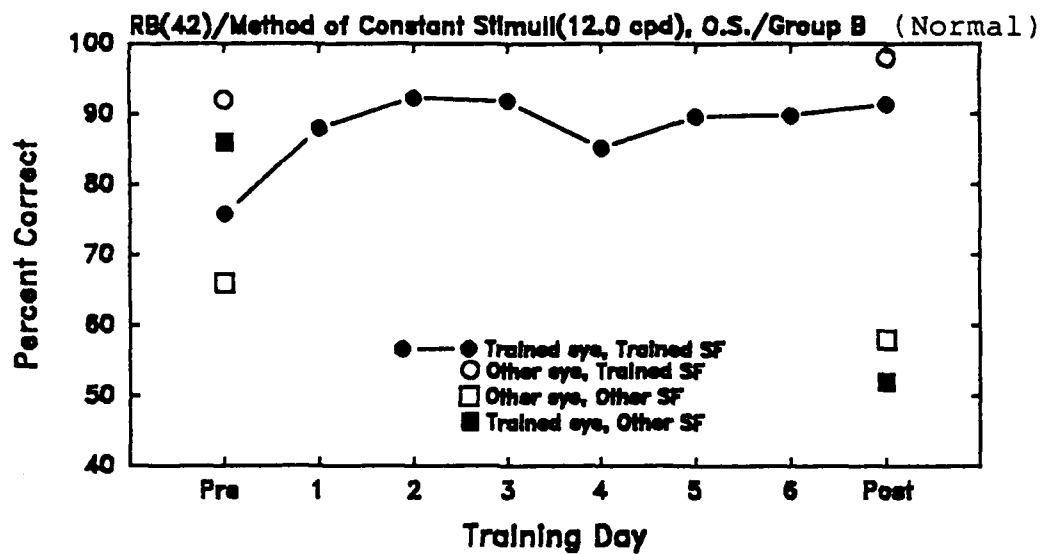


Figure 11

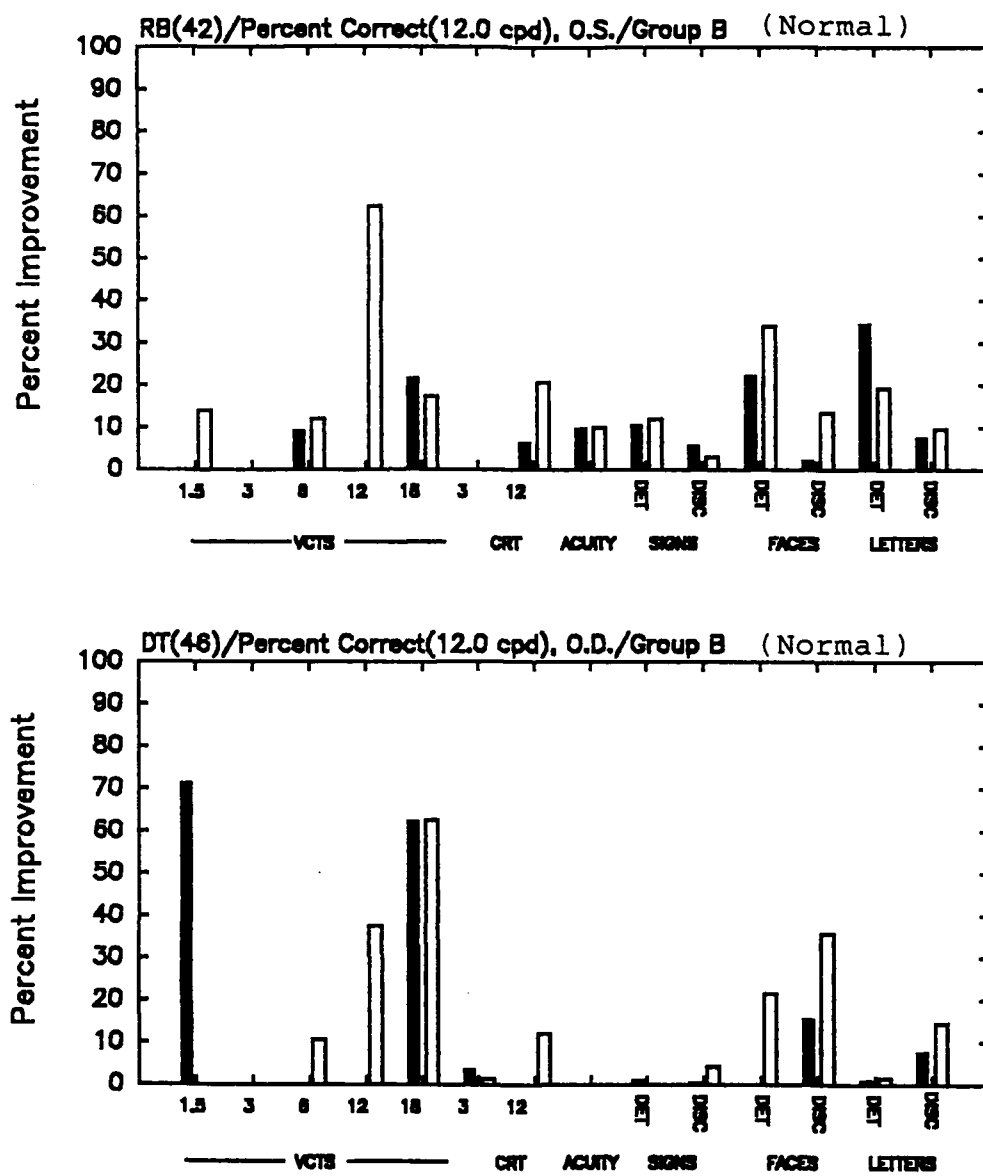


Figure 12

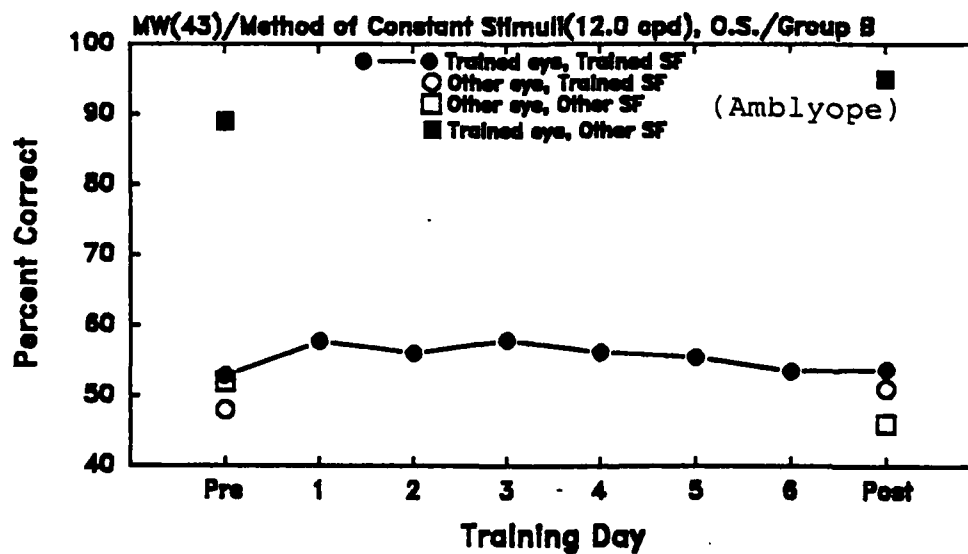
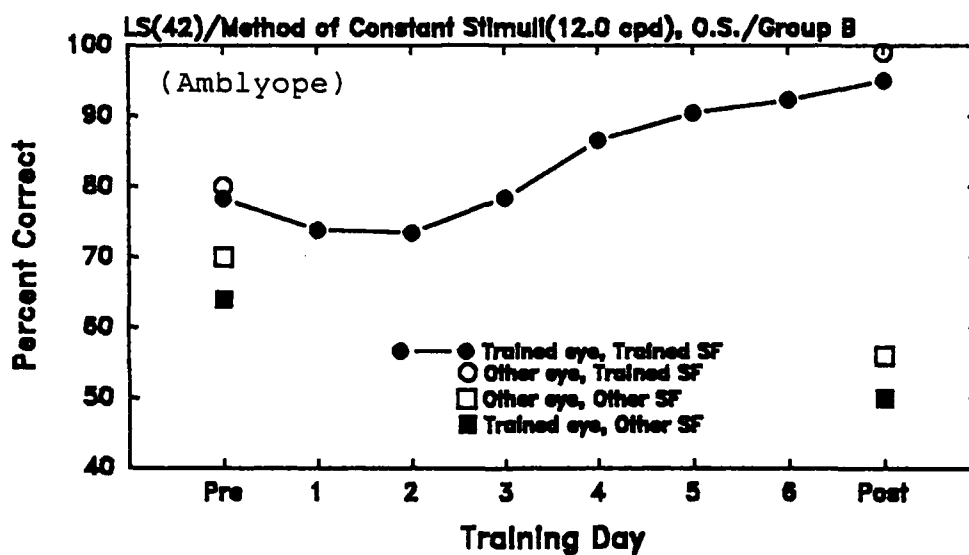
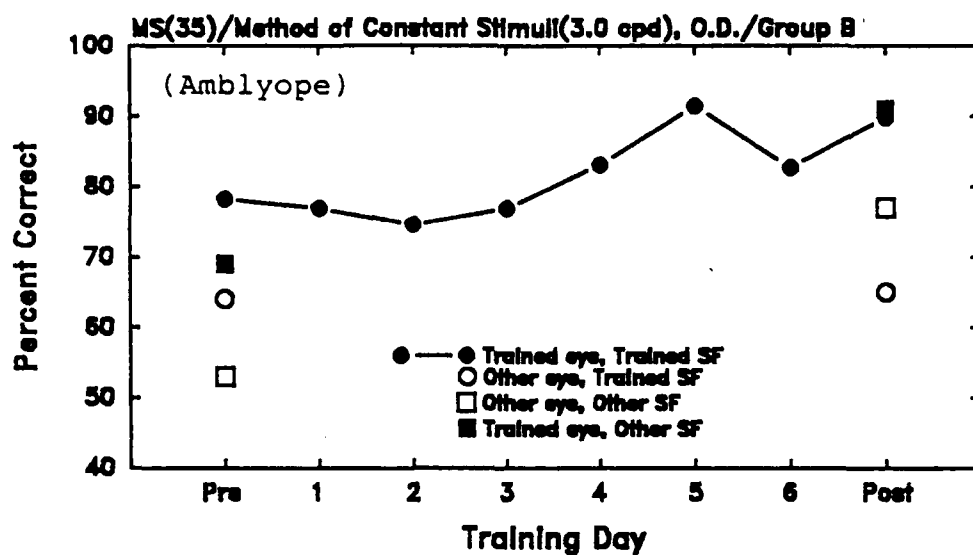


Figure 13

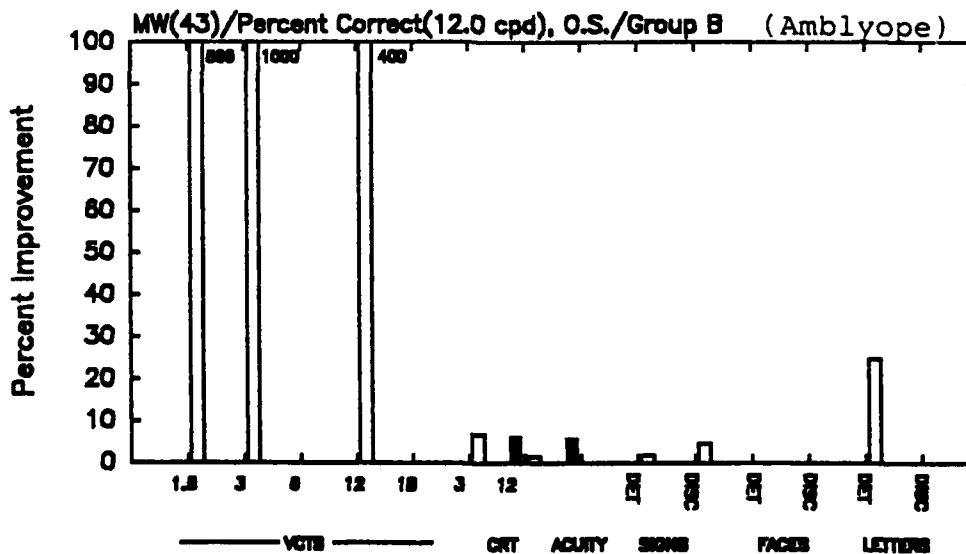
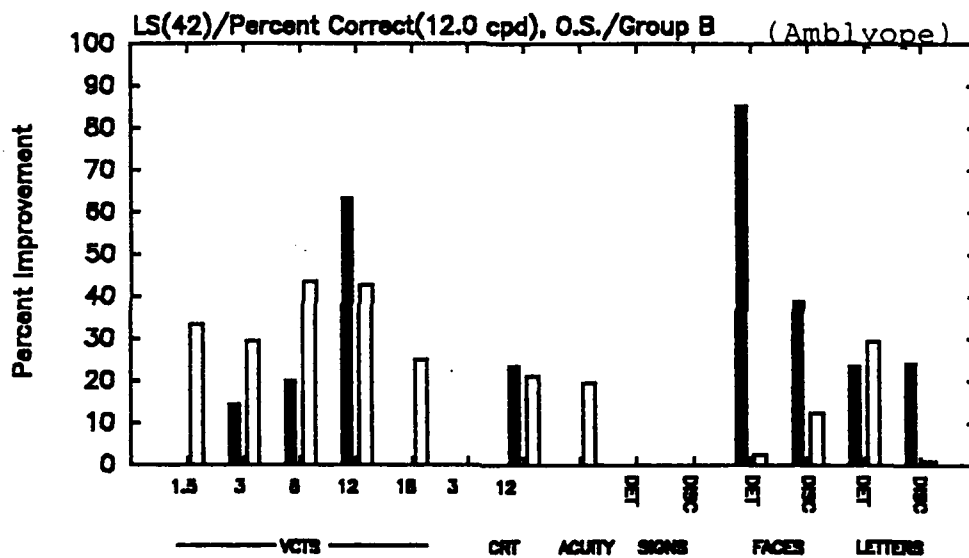
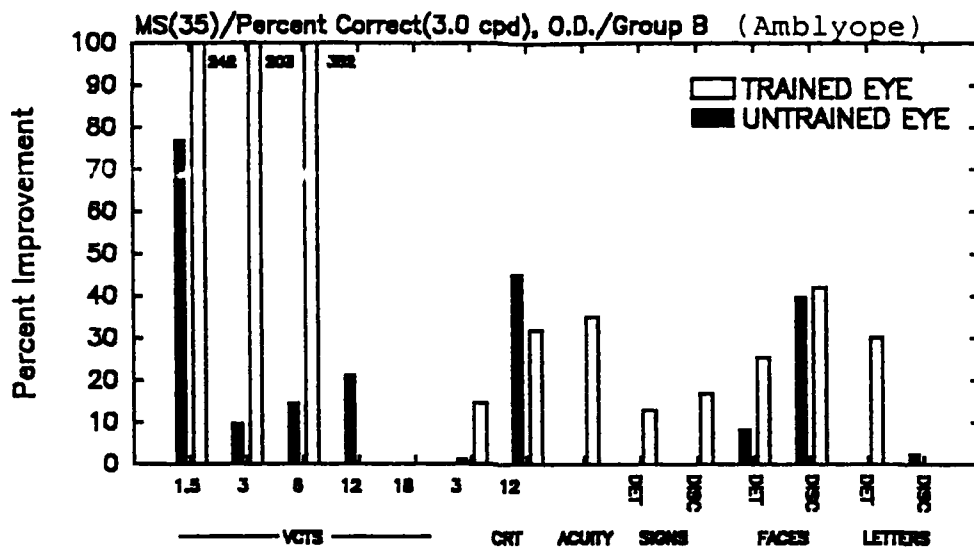


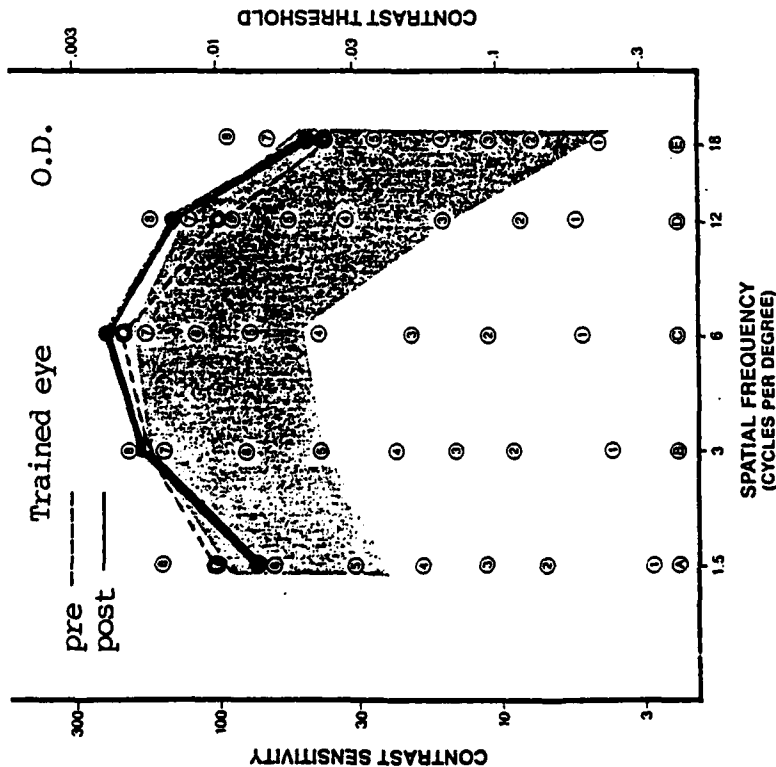
Figure 14



VISTECH CONSULTANTS, INC.
Contrast Sensitivity
EVALUATION FORM



VISTECH CONSULTANTS, INC.
Contrast Sensitivity
EVALUATION FORM



OBSERVER NAME LM (38) DATE 1990
VCTS* SYSTEM USED _____ TESTING DISTANCE _____
COMMENTS: trained at 12 cpd
normal

Tested by: _____

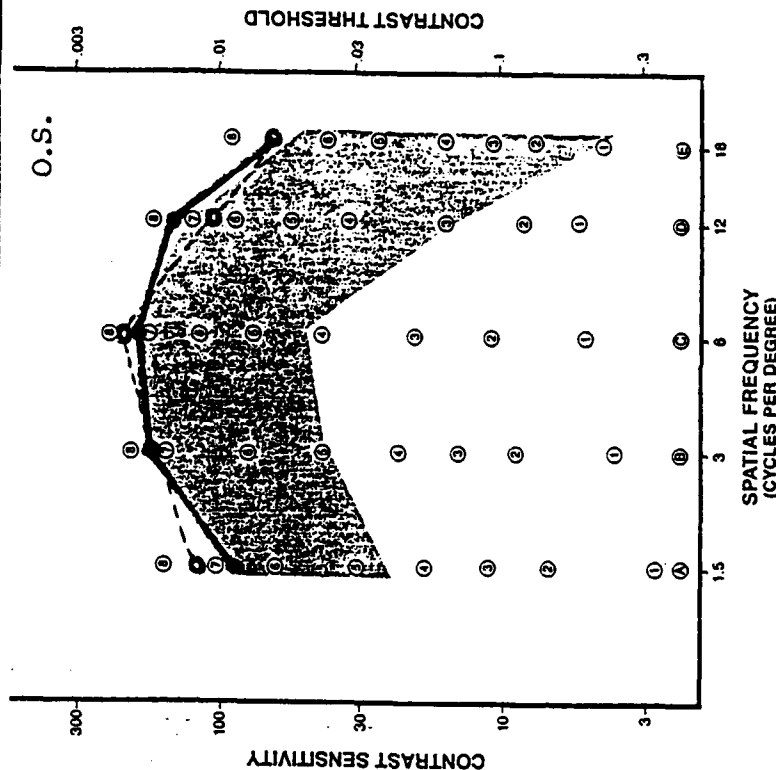
The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the Instruction Booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due strictly to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

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VISTECH FORM 0064

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OBSERVER NAME _____ DATE _____
VCTS* SYSTEM USED _____ TESTING DISTANCE _____
COMMENTS: _____

Tested by: _____

The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the Instruction Booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due strictly to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

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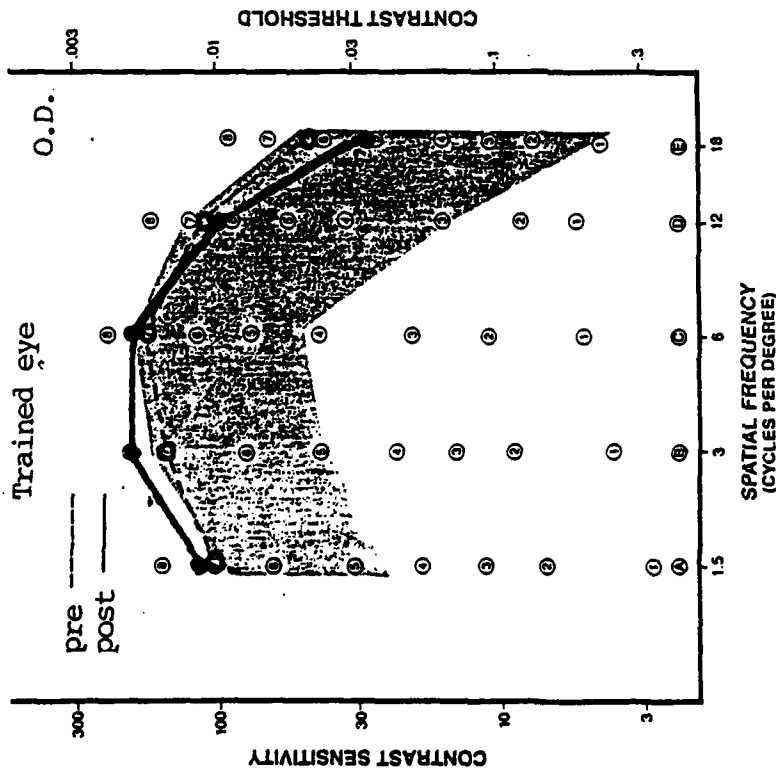
Figure 15



VISTECH CONSULTANTS, INC.
Contrast Sensitivity
EVALUATION FORM



VISTECH CONSULTANTS, INC.
Contrast Sensitivity
EVALUATION FORM

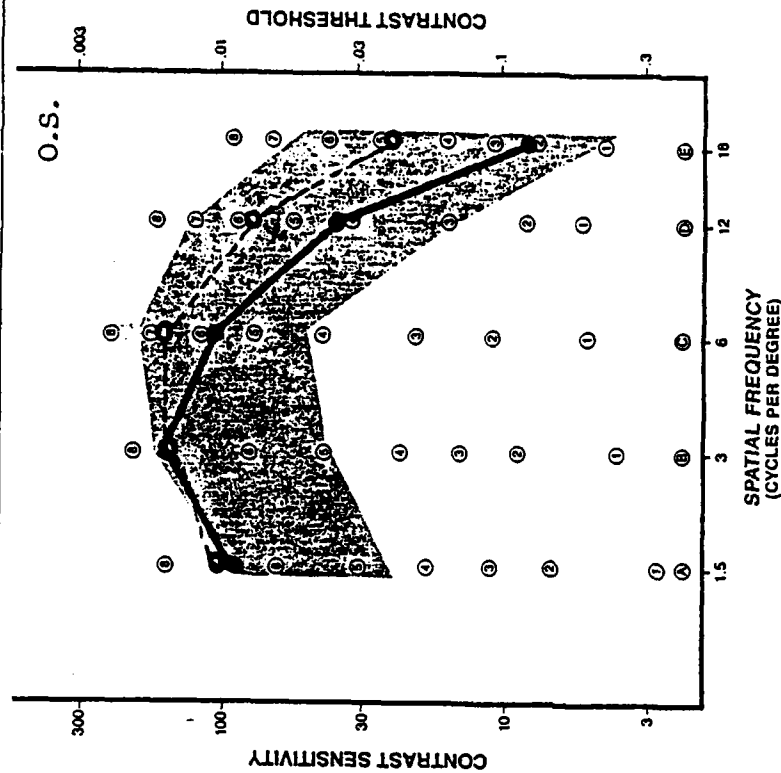


OBSERVER NAME IH (62) DATE 1990
VCTS* SYSTEM USED _____ TESTING DISTANCE _____
COMMENTS: trained at 3 cpd
normal

Tested by: _____

The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the Instruction Booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due solely to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

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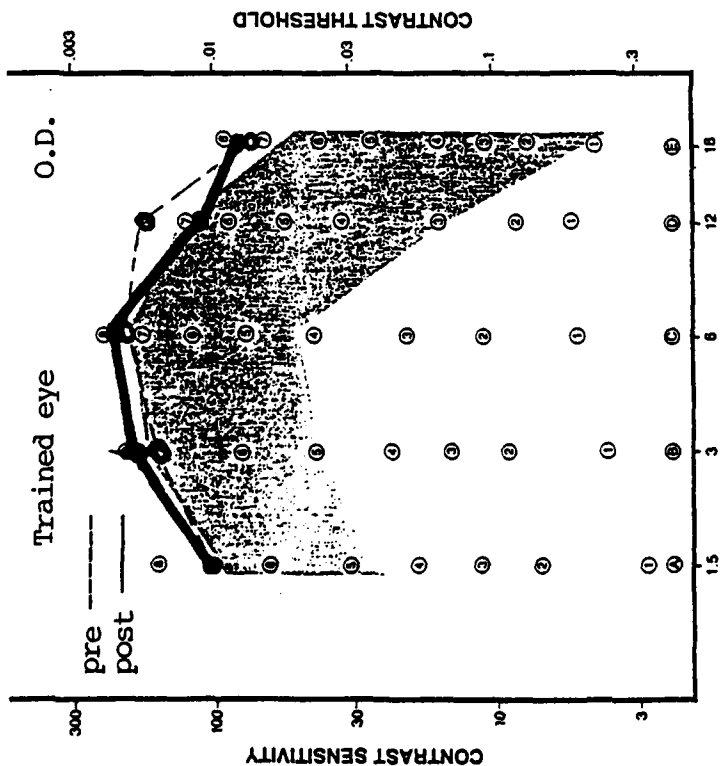
OBSERVER NAME _____ DATE _____
VCTS* SYSTEM USED _____ TESTING DISTANCE _____
COMMENTS: _____

Tested by: _____

The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the Instruction Booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due solely to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

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Figure 16



OBSERVER NAME SK (50) DATE 1990

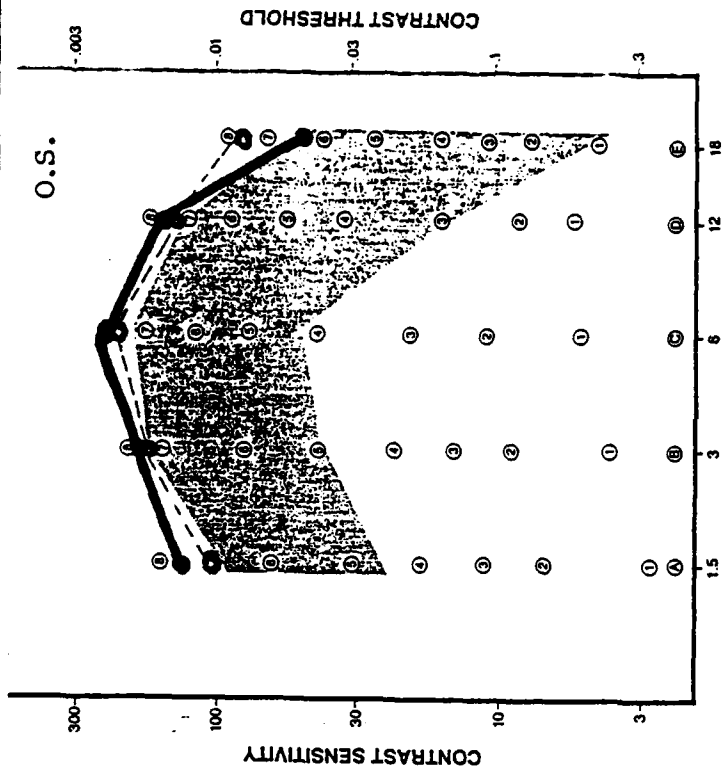
VCTS* SYSTEM USED _____ TESTING DISTANCE _____

COMMENTS: trained at 3 cpd

normal

Tested by: _____

The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the Instruction Booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due strictly to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.



OBSERVER NAME _____ DATE _____

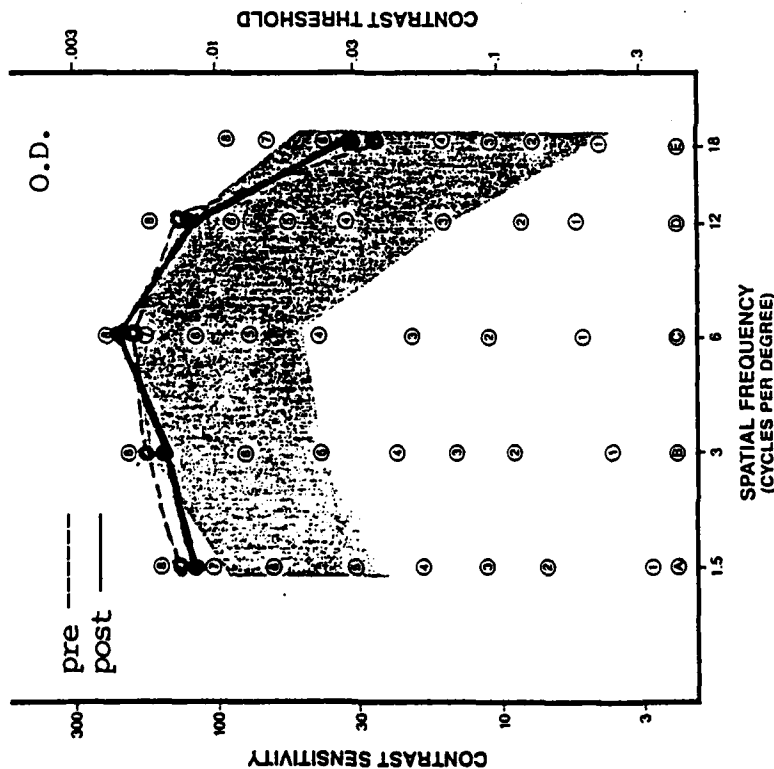
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COMMENTS: _____

Tested by: _____

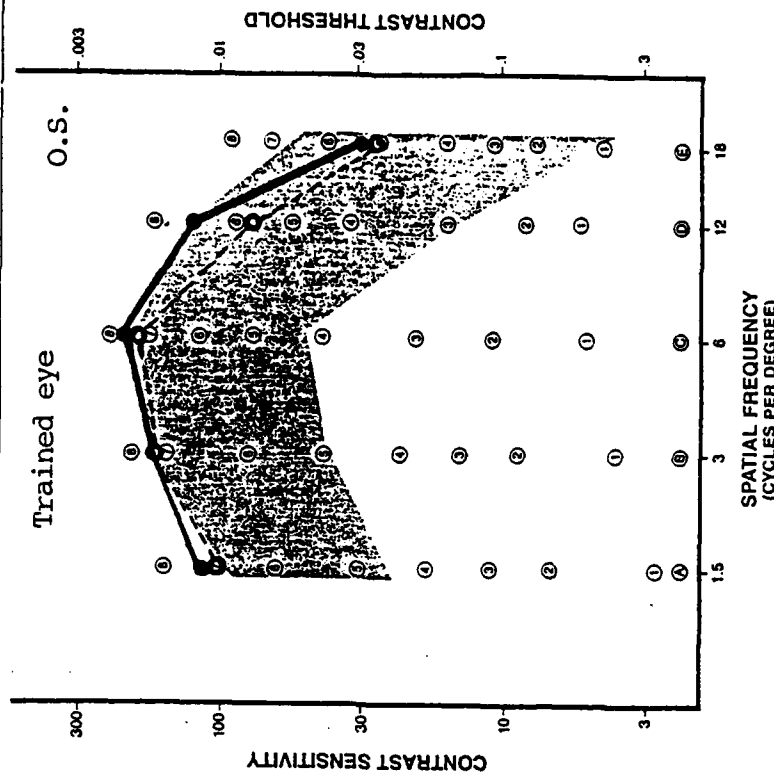
The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the Instruction Booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due strictly to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

Figure 17



OBSERVER NAME RB (42) DATE 1990
 VCTS® SYSTEM USED _____ TESTING DISTANCE _____
 COMMENTS: trained at 12 cpd
normal

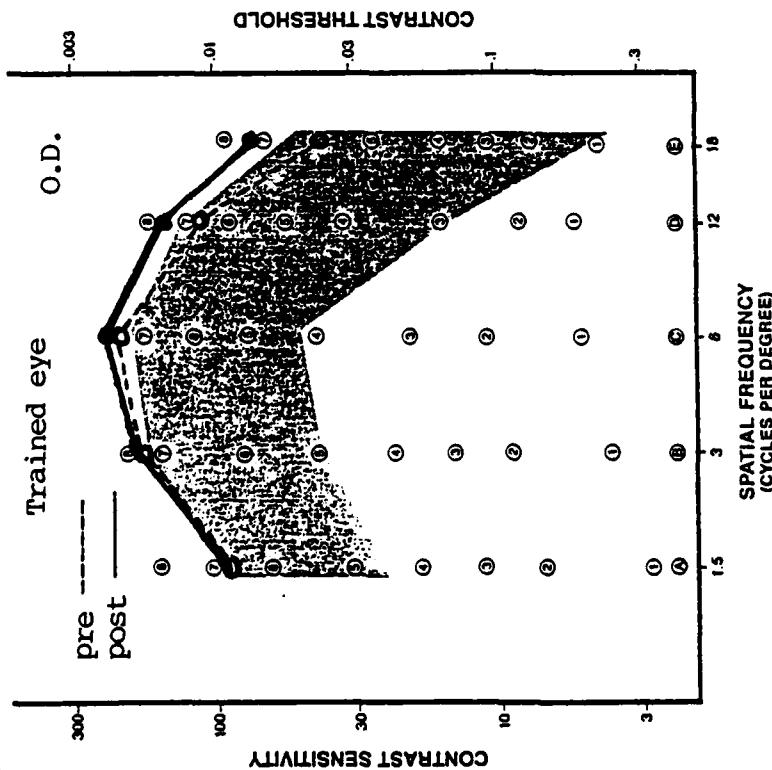
Tested by: _____
 The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the Instruction Booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due to a visual problem, but it may also be due to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.



OBSERVER NAME _____ DATE _____
 VCTS® SYSTEM USED _____ TESTING DISTANCE _____
 COMMENTS: _____

Tested by: _____
 The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the Instruction Booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due to a visual problem, but it may also be due to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

Figure 18.

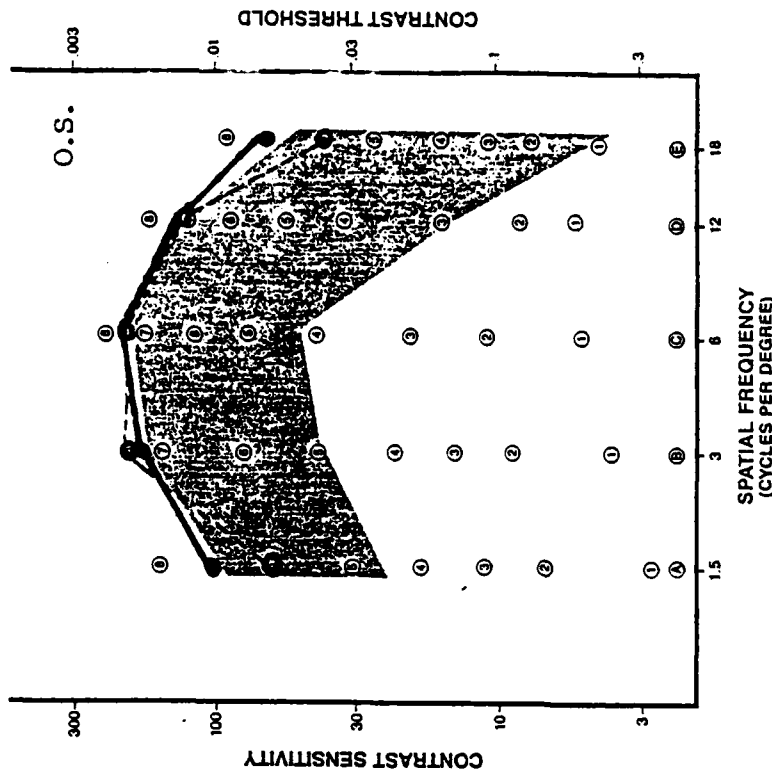


OBSERVER NAME Dt (46) DATE 1990
 VCTS* SYSTEM USED _____ TESTING DISTANCE _____
 COMMENTS: trained at 12 cpd
normal

Tested by: _____

The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the Instruction Booklet. It is provided to help AD in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due strictly to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

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OBSERVER NAME _____ DATE _____
 VCTS* SYSTEM USED _____ TESTING DISTANCE _____
 COMMENTS: _____

Tested by: _____

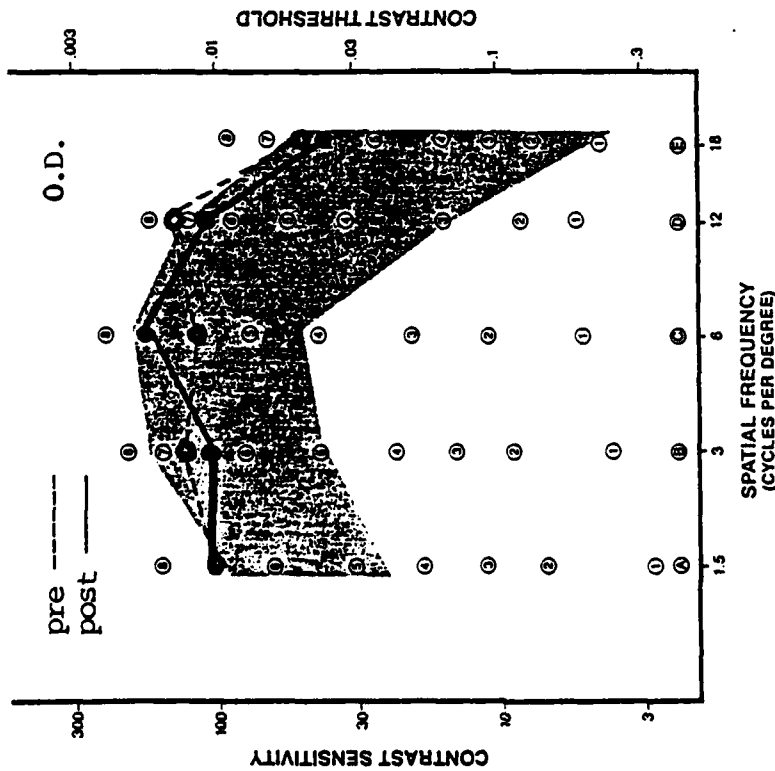
The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the Instruction Booklet. It is provided to help AD in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due strictly to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

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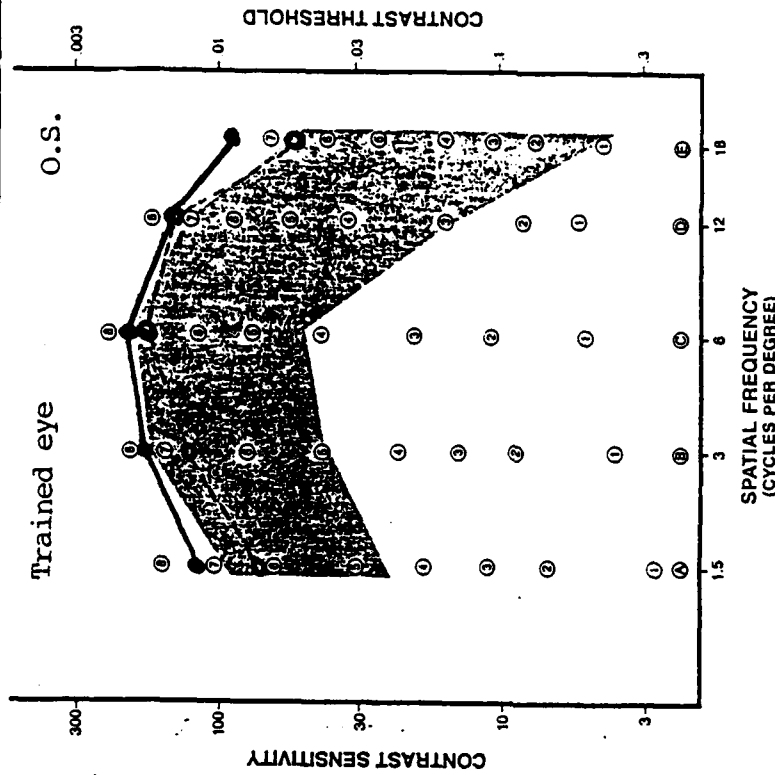
Figure 19



OBSERVER NAME JC (48) DATE 1990
 VCTS* SYSTEM USED _____ TESTING DISTANCE _____
 COMMENTS: trained at 3 cpd
normal

Tested by: _____

The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the Instruction Booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due strictly to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

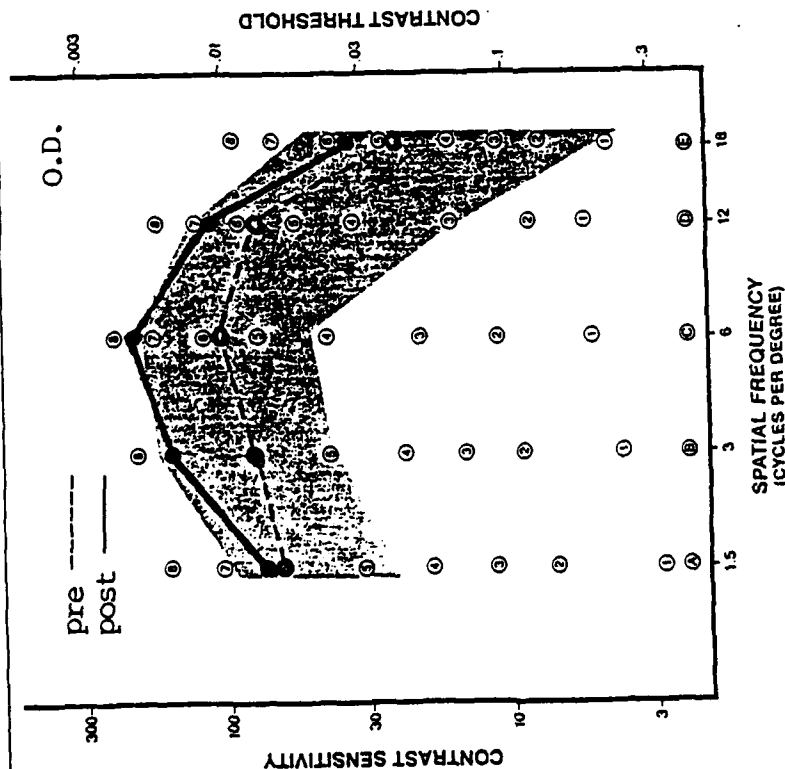


OBSERVER NAME _____ DATE _____
 VCTS* SYSTEM USED _____ TESTING DISTANCE _____
 COMMENTS: _____

Tested by: _____

The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the Instruction Booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due strictly to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

Figure 20

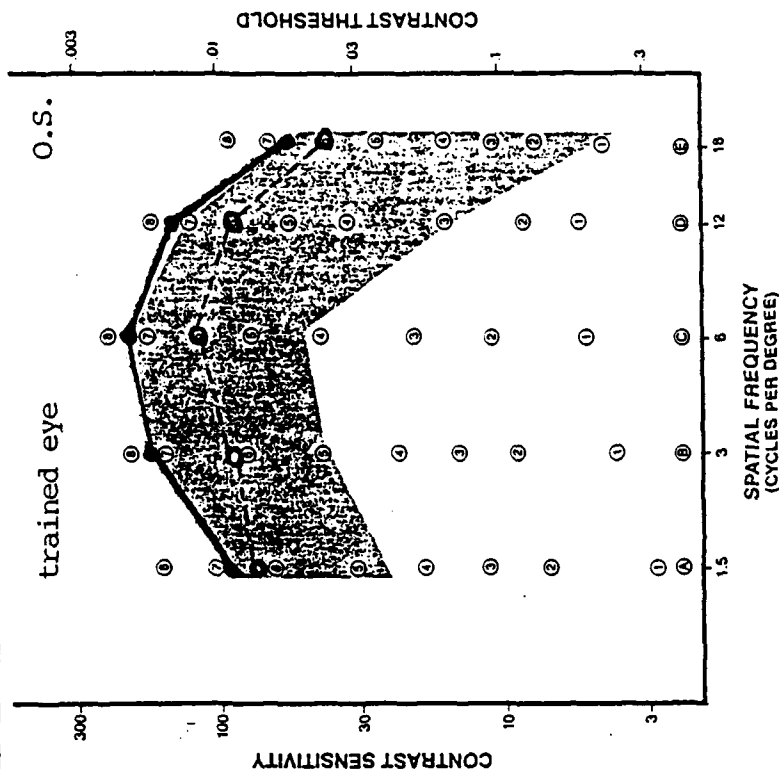


OBSERVER NAME CH (51) DATE 1990-
 VCTS* SYSTEM USED _____ TESTING DISTANCE _____
 COMMENTS: trained at 3 cpd
normal

Tested by: _____

The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the instruction booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due strictly to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

VISTECH CONSULTANTS, INC. 1988



OBSERVER NAME _____ DATE _____
 VCTS* SYSTEM USED _____ TESTING DISTANCE _____
 COMMENTS: _____

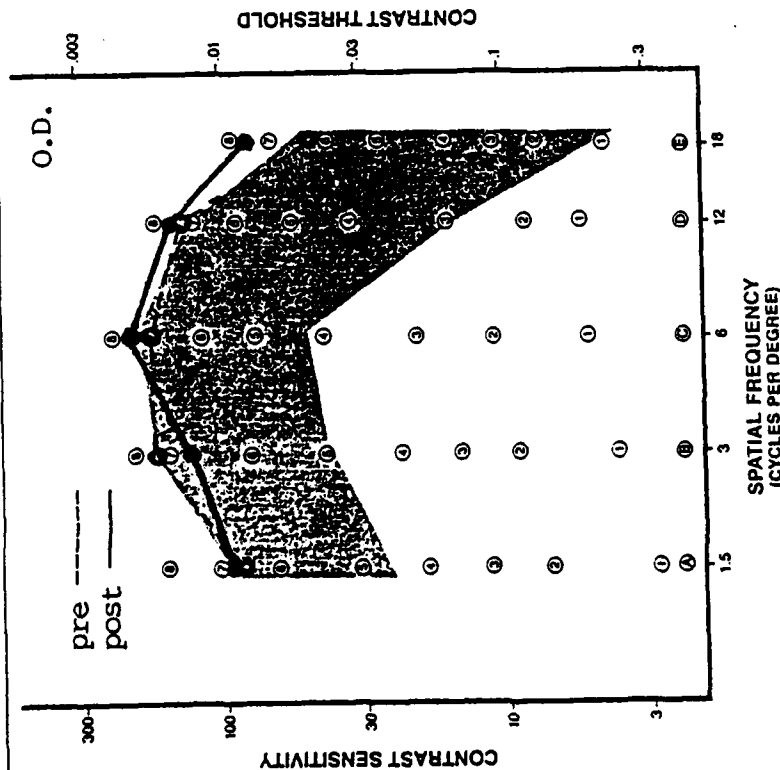
Tested by: _____

The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the instruction booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due strictly to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

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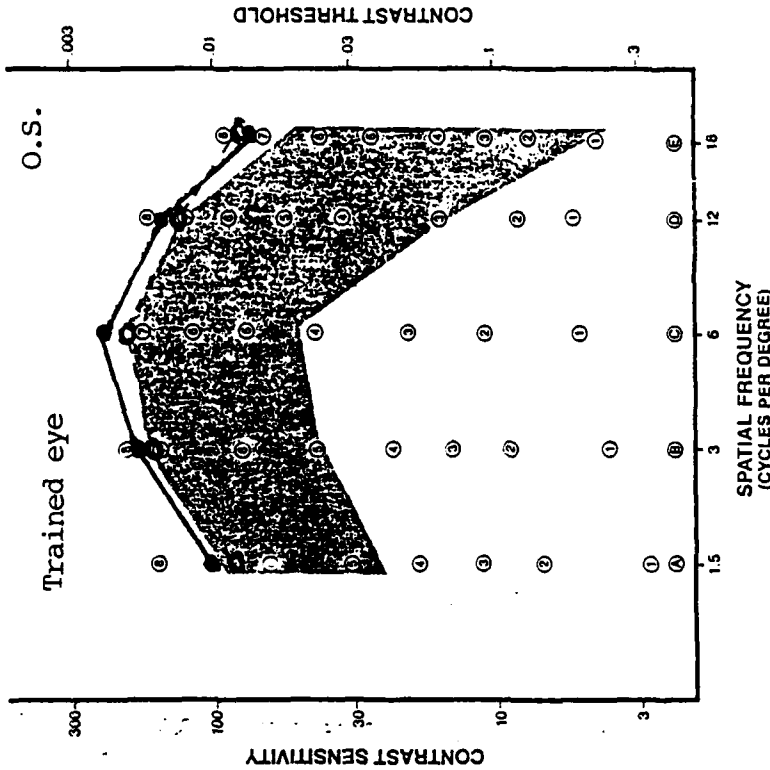
Figure 21



OBSERVER NAME PM (48) DATE 1990
 VCTS® SYSTEM USED _____ TESTING DISTANCE _____
 COMMENTS: trained at 12 cpd
normal

Tested by: _____

The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the Instruction Booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due strictly to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

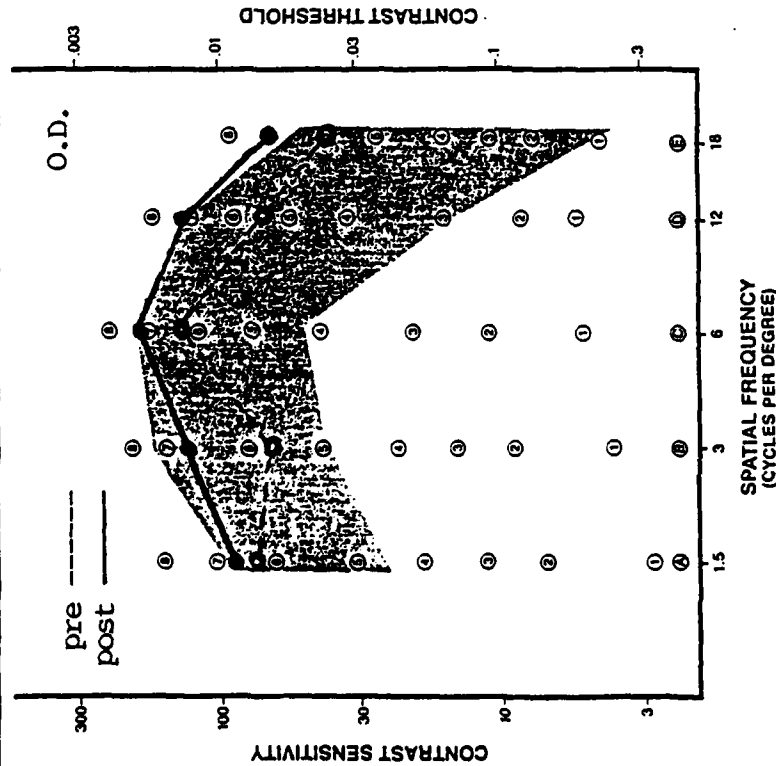


OBSERVER NAME _____ DATE _____
 VCTS® SYSTEM USED _____ TESTING DISTANCE _____
 COMMENTS: _____

Tested by: _____

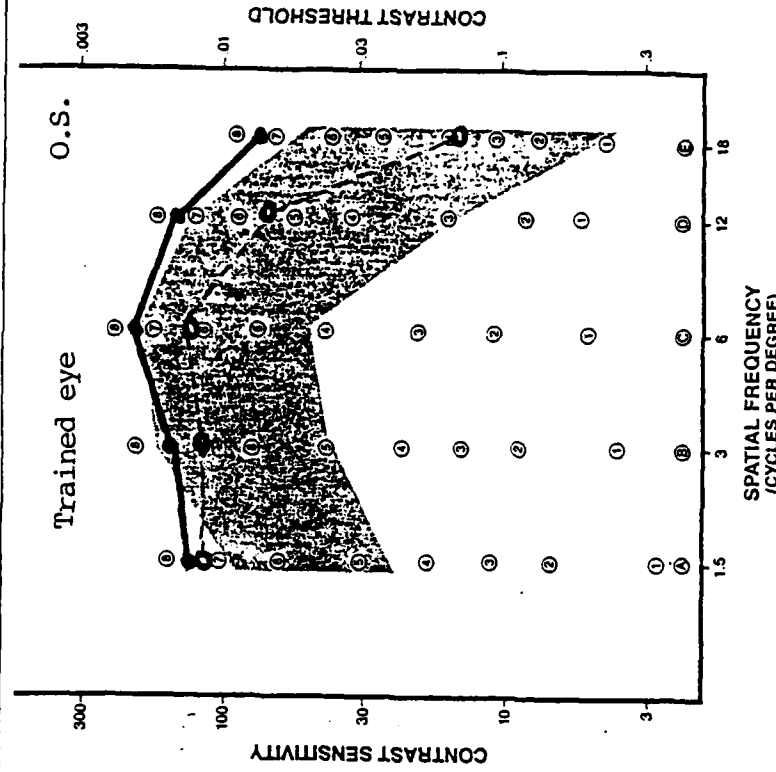
The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the Instruction Booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due strictly to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

Figure 22



OBSERVER NAME JS (48) DATE 1990
 VCTS* SYSTEM USED TESTING DISTANCE
 COMMENTS: trained on 3 cpd
normal

Tested by: _____
 The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the instruction booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due strictly to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.



OBSERVER NAME _____ DATE _____
 VCTS* SYSTEM USED _____ TESTING DISTANCE _____
 COMMENTS: _____

Tested by: _____
 The normal range of contrast sensitivity is shown in the gray area. The normal range is only relevant if proper lighting is used as described in the instruction booklet. It is provided to help AID in the diagnosis of optical, neurological, or pathological disorders and should not be used as a sole criterion for diagnosis and treatment. In some cases, depressed contrast sensitivity is due strictly to normal variation and not to an optical, neurological, or pathological problem. For this reason, contrast sensitivity should be used in conjunction with other diagnostic techniques.

Figure 23

Table 1 Contrast sensitivity before and after training in normals

		Obs	CRT pre	CRT post	VCTS pre	VCTS post

Trained at 3.0 cpd						

High	LH		217	245.2	170	220
Sensitive	HK		210	283.9	175	220
	JS		149.3	111.5	158.3	170
Low	SK		68.6	94.7	170	203.3
Sensitive	CH		100	149.3	93	186.7
	JC		100	177.4	158.3	203.3

Trained at 12.0 cpd						

High	PM		80	93.9	127.7	155
Sensitive	AC		79.4	100.2	127.7	140
	DT		75.7	93	112.7	155
Low	LM		55.5	61.9	100.3	140
Sensitive	RB		60.79	102.9	77	125

Table 2 Contrast sensitivity before and after training in amblyopes

Obs	CRT pre	CRT post	VCTS pre	VCTS post
Trained at 3.0 cpd				
MS	43.4	49.7	37.3	113.3
CW	47.8	81	37.3	85
Trained at 12.0 cpd				
MW	2.9	2.98	1	5
LS	32.6	16.5	66	81.7
CR	83.4	119.1	125	115.3